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BUILDING OUR FUTURE

Report
Digital Modelling

Research Project No: 2005-001-C-9

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PREFACE

The Cooperative Research Centre for *Construction Innovation* is a national research, development and implementation centre focused on the needs of the property, design, construction and facility management sectors. Established in 2001 and headquartered at Queensland University of Technology as an unincorporated joint venture under the Australian Government's Cooperative Research Program, *Construction Innovation* is developing key technologies, tools and management systems to improve the effectiveness of the construction industry. *Construction Innovation* is a seven year project funded by a Commonwealth grant and industry, research and other government support. Approximately 400 personnel and an alliance of 21 participants are involved in and support the activities of *Construction Innovation*.

There are three research areas:

- Program A - *Business and Industry Development*
- Program B - *Sustainable Built Assets*
- Program C - *Delivery and Management of Built Assets*

Underpinning these research programs is an *Information Communication Technology* (ICT) Platform.

Each project involves at least two industry partners and two research partners to ensure collaboration and industry focus is optimised throughout the research and implementation phases. The complementary blend of industry partners ensures a real-life environment whereby research can be easily tested and results quickly disseminated.

This research report (Report 2005-001-C-9) is part of a series of reports for the Sydney Opera House – FM Exemplar Project and provides the finding of the Digital Modelling research stream. This report compiles and summarises the previous work included in reports 2005-001-C-3, 4 and 5.

ABREVIATION USED IN THIS REPORT

AEC/FM	Architecture Engineering, Construction and Facilities Management
AM	Asset Management
ACI	Asset Condition Index
API	Application Programming Interfaces
BCI	Building Condition Index
BFI	Building Fabric Index
BIMSS	Building Information Model Specification
BLIS	Building Lifecycle Interoperable Software
BPI	Building Presentation Index
CAD	Computer Aided Design
CAFM	Computer Aided Facilities Management
CAVS	Communications and Audio-Visual Services
CIFE	Centre for Integrated Facilities Engineering at Stanford
FCI	Facilities Condition Index
FM	Facilities Management
GSA	General Services Administration
IAI	Alliance for Interoperability
IFC	Industry Foundation Classes
POPE	Place of Public Entertainment
PSET	Standard Property Sets
SABLE	Simple Access to the Building Lifecycle Exchange
STEP	Standard for the Exchange of Product Data
TIC	Technical Information Coordinator

EXECUTIVE SUMMARY

Overview

This Digital Modelling Report incorporates the previous research completed for the FM Exemplar Project utilising the Sydney Opera House as a case study. The research has demonstrated significant benefits in digitising design documentation and operational and maintenance manuals. Since Sydney Opera House do not have digital models of its structure, there is an opportunity to investigate the application of Digital Facility Modelling using standardised Building Information Models (BIM).

The digital modelling research project has examined the potential of standardised building information models to develop a digital facility model supporting facilities management (FM). The focus of this investigation was on the following areas:

- The re-usability of standardised building information models (BIM) for FM purposes.
- The potential of BIM as an information framework acting as integrator for various FM data sources.
- The extendibility and flexibility of the BIM to cope with business specific data and requirements.
- Commercial FM software using standardised building information models.
- The ability to add (organisation-specific) intelligence to the model.
- A roadmap for Sydney Opera House to adopt BIM for FM.

Findings and Deliverables

The FM Exemplar Project has established that a BIM is an appropriate and potentially beneficial technology enabling storage and retrieval of integrated building, maintenance and management data for Sydney Opera House. Using this approach several advantages can be envisioned: consistency in the data, intelligence in the model, multiple representations (such as 2d, 3d, reports, etc), an integrated source of information for existing software applications, integrated queries for data mining, etc. The standardised building model acts as main data structure which can be extended with other data sources as each element (wall, furniture, room, grouping elements) has a unique Identifier. This unique identifier can be used to correlate different datasets opening up query capabilities across different datasets.

The industry foundation classes (IFC) – open building exchange standard – specification provides comprehensive support for asset and facilities management functions, and offers new management, collaboration and procurement relationships based on sharing of intelligent building data. The major advantages of using an open standard are: information can be read and manipulated by any compliant software, reduced user “lock in” to proprietary solutions, third party software can be the “best of breed” to suit the process and scope at hand, standardised BIM solutions consider the wider implications of information exchange outside the scope of any particular vendor, information can be archived as ASCII files for archival purposes, and data quality can be enhanced as the now single source of users’ information has improved accuracy, correctness, currency, completeness and relevance.

The current availability of FM applications based on BIM is in its infancy but focussed systems are already in operation internationally and show excellent prospects for implementation systems at Sydney Opera House.

To support the FM processes using the IFC, guidelines and modelling practices have been formalised in the form of a Sydney Opera House specification was developed. This specification describes how Sydney Opera House specific information and conventions can be incorporated in the BIM. This enables Sydney Opera House to develop a BIM with consistency.

Tests with partial BIM data demonstrated that the creation of a complete Sydney Opera House BIM is realistic, but subject to resolution of compliance and detailed functional support by participating software applications.

The showcase has demonstrated successfully that IFC based exchange is possible with several common BIM based applications through the creation of a new partial model of the building. Data exchanged has been reasonably geometrically accurate, notwithstanding that Sydney Opera House's structure represents some of the most complex building elements and supports rich information describing the types of objects, with their properties and relationships. The unexpected re-use of a structural model of the Sydney Opera House for FM clearly demonstrates the re-usability of the IFC.

The structural model has been imported from an architectural computer aided design (CAD) system where the IFC model was enriched with spatial element such as Rooms and Furniture elements based on the Sydney Opera House specification. This clearly demonstrates the extendibility of the IFC. Based on this enriched IFC file a showcase system has been developed where the Sydney Opera House information can be visualised and re-structured. Facilities performance and cleaning contract data has been inserted and correlated with the IFC model offering functionality to query and to get visual feedback of this correlated dataset.

The following conclusions were made:

- Standardised BIM systems as an integrated information source for FM delivery including business processes is feasible.
- IFC offers interoperability between CAD systems enabling re-use of building information.
- The IFC model is standardised and consequently can be used by a variety of different software systems including FM systems.
- Commercial FM software systems are available using IFC data.
- Other related software such as energy prediction models and on-site monitoring are available using IFC data.
- The IFC model is extensible and can incorporate organisation specific requirements.
- Integrated datasets can be constructed offering enhanced query results and enhanced visualisation of (integrated) datasets.

It is recommended that the FM industry adopt IFC for the sharing of FM information for asset management (AM) applications.

1. Objectives and Scope

1.1 Introduction

The Facilities Management (FM) Exemplar Project utilises Sydney Opera House was initiated by the FM Action Agenda, as supported by the Australian Government's Department of Industry, Tourism and Resources, Sydney Opera House and Transfield Services, and delivered by the Cooperative Research Centre for *Construction Innovation* (*Construction Innovation*) along with Rider Hunt Terotech, CSIRO, University of Sydney, FMA Australia and other industry and educational partners. The project's three research themes as crucial in improving the performance of FM as follows:

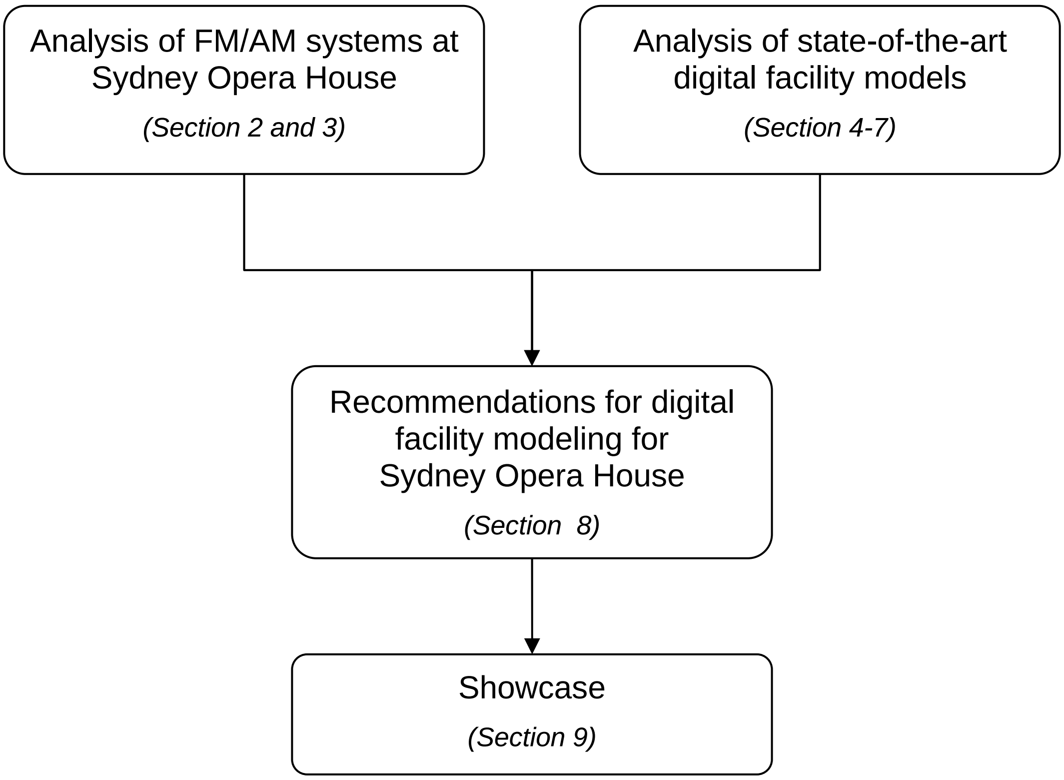
- *Digital modelling research* aims to develop a digital model based on the 3D digital building information models to assist in the integration and automation of FM.

- *Services procurement research* aims to develop a performance based procurement framework for FM service delivery. Service requirements are defined in terms of performance objectives, assessment techniques and decision making strategies.

- *Performance benchmarking research* aims to develop an FM benchmarking framework that comprises performance measures, methods and procedures, and deliver benchmarks which enable facilities / organisations to identify best practice and improvement strategies.

Additionally the project aimed to achieve collaboration across these three areas as a basis for demonstrating FM as a business enabler.

This document describes the results of the investigation into develop digital modelling to support FM at Sydney Opera House. The investigation was setup as follows:



This specification has been written as instructions to participants contributing to or using the system.

The analysis of FM/AM systems at Sydney Opera House has resulted in the following sections

- Section 2 discusses the existing software systems to support asset and facilities management at Sydney Opera House.
- Section 3 describes and analyses Sydney Opera House's building document systems.

The analysis of state-of-the-art digital facility models has resulted in the following sections:

- Section 4: Building Information Models introducing an emerging new way of dealing with building information and its advantages.
- Section 5: Industry take-up of Building Information Model analysing the current uptake of BIM by the industry.
- Section 6: Facility Management Support for IFC, especially supporting AM / FM processes.
- Section 7: IFC Compliant Software for FM analysis several commercially available FM tools based on the IFC.

The research 'recommendations for Digital Facility Modelling for Sydney Opera House' has resulted in an extensive building information specification especially designed for Sydney Opera House which can be used as an example for other buildings (Section 8: BIM specifications for Sydney Opera House)

To demonstrate the potential and to check the validity of the recommendations a showcase has been developed which can be found in Section 9.

Section 10 summarises the findings and the recommendations.

2. Facilities Management (FM) Systems at Sydney Opera House

2.1 Existing FM Systems

Current systems at Sydney Opera House are as follows:

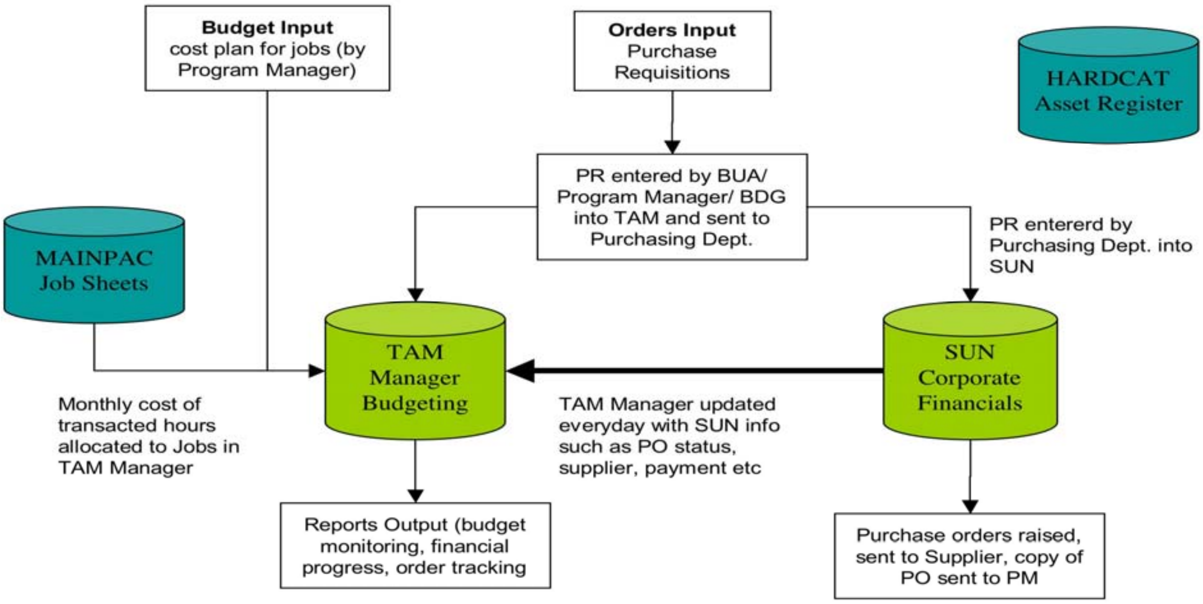


Figure 1: Existing AM systems

Function	Product	Comments
Building maintenance	**MAINPAC**	Job sheets, recording labour/hour transactions are managed by the system. Records performance measures (eg average time for alteration etc)
Asset Register	**HARDCAT**	The financial asset register, which monitors the value of the asset at any given time. Uses depreciation rates to calculate current value. Annual asset audits are performed through this system.
SAM Budgeting	**TAM Manager**	System established in 2000, with data from 2001 to date considered reliable. Setting up and monitoring of major and regular works budgets, order commitments and actual spend. Ensures that projects are completed within the allocated budget.
Accounting	**Sun**	Corporate Financial system
Building Condition	**FaPI**	SQL database, updated weekly or quarterly with a rating of the presentation of the building.
Document Management	**TRIM**	Business document management tool. (Adapted by the Facilities Portfolio as an interface to Sydney Opera House pdf drawings linked to an MS Access database)
Technical Document access	**Intranet**	An Intranet is being introduced to provide universal access to Sydney Opera House technical information

Table 1: Existing FM Systems

2.2 Assets

An asset is anything with a value of greater than A$5,000. All assets are bar-coded (approximately 7500 in number). Currently assets are classified according to 14 functional zones (FS, see below). The level of detail is determined by the frequency of activity (e.g. lifts are identified individually because of the volume of repair).
An asset audit is carried out annually.

2.3 Maintenance

Maintenance is complicated at Sydney Opera House due to the nature of the building, a high level of building services and operational requirements which severely limit access to operational areas. Maintenance is divided into two categories *Preventative* and *Corrective* (ad hoc). A key element of the maintenance services is the Operations Centre which is the first point of contact for any problem on the site. 10-20 corrective jobs are carried out daily, with approximately 200 jobs total per week. 40 external staff and 25 in-house staff are employed on maintenance.

Maintenance is organised into four technical groups:

- electrical
- mechanical (including stage gear etc)
- building
- communications and audio–visual services (CAVS)

2.4 Statutory Compliance

The facility is required to be certified for Place of Public Entertainment (POPE) and much change has occurred to these regulations since the building was originally commissioned.
BCA compliance is also required with significant impact in public areas such as egress lighting etc.

2.5 Building Presentation

To address the ageing of the facility (almost 30 years of intense usage) a measure of the visual presentation of key public areas has been established, as part of a priority AM initiative. Technical standards have been developed, such as a building presentation index (BPI), to regularly monitor this aspect.

Contracted maintenance work can be monitored via quality assurance systems and / or internal or external audits.

2.6 Strategic Plan

A 25 year Total Asset Management (TAM) plan is in place, with an estimated yearly 2006-2007 to 2030-2031 budget of $51 million (average per annum, estimated and escalated).

The current approved maintenance budget is however $19 million, with a breakdown as follows:

- regular maintenance $8 million
- major works $11 million

For regular maintenance $5 million is carried out on contract, with $3 million by Sydney Opera House in-house team.

2.7 External Services

The ongoing planned maintenance services are undertaken by external Contractors for each of the four technical elements, e.g. electrical, mechanical, building and CAVS.

Contractors are engaged on term contracts.

Currently none of the TAM/FM systems are integrated. Although not integrated, consistency is maintained between systems.

There are no connections to the four main external contractors and all updating of Sydney Opera House TAM/FM data has been done to-date manually by Sydney Opera House staff. Outside contractors are now required to use in-house systems, reducing this waste of resources.

A future system would permit direct sharing of data and updating.

3. Building Documentation Management

3.1 History

Commencing in 1958, the project documentation was based on hardcopy paper and pencil/ink drawings, pre-dating even the introduction of 2D CAD technology. While excellent catalogues of this information are available, accurate data is extremely limited, in hardcopy, microfilm or digital format.

At the end of Stage I of the construction in 1966, accurate surveys (in decimal feet units) of the then current infrastructure of the ground works and podium was carried out and to date these are the definitive data of those parts of the facility.

3.2 Nature of Sydney Opera House

As the exterior of unique curved shells implies, Sydney Opera House is a large, very complex structure, housing equipment and activities that are equally complex. The building comprises 7 theatres, 37 plant rooms, 12 lifts, over 1000 rooms; the building has 300 full-time staff with 500-600 part-time staff, delivering over 1500 performance and 1000 other events per annum.

The building has a design life of 250 years and a very high quality of construction and finish appropriate for NSW's most prestigious entertainment facility.

The building has a Conservation order and is likely to have a UNESCO World Heritage listing, further complicating the process of change and renewal.

Its early structural and spatial layout was a design challenge for the design and construction team, and innovation was a common theme of the eventual technical solution for many aspects of the final design.

The consequence is that traditional 2D documentation was hard pressed to adequately describe the work to be constructed; and although this may have been rather more adequately resolved by the geometric capability and accuracy of 2D CAD software, unfortunately the building construction pre-dated the emergence of this technology.

3.3 CAD Drawings

The final drawings were converted to CAD (by tablet digitisation of the hardcopy plans) in the late 80s just as this technology was becoming adopted in the industry. However, for example, floor plans converted at that time are unreliable and are not co-ordinated over different levels.

Consequently all works that need accurate descriptions of the existing building have to be re-measured by the relevant contractor carrying out the work. This has lead to a significant degree of wasted work, and should be addressed in any new documentation initiative.

The lack of consistent, reliable data has become a major problem after 30 years of occupancy, particularly many services system modifications, numerous small works projects and now, the need for significant renewal and related building updates.

Redevelopment of the base building is hampered because of the poor quality of CAD data.

To develop a 2D CAD database today requires a major investment as the foundation of this work will be a complete re-survey and re-documentation.

3.4 Survey Markers Project

To address the lack of good drawings and to develop a strong platform for future work, a series of survey marks (169) have been established, with brass pins identified by the location (see BIMSS: Coordinate System, p4) and geographic coordinates. This will ensure accurate placement of new work and guide all future measurement and technical documentation.

3.5 Digital Models

Sydney Opera House has no current BIM of their facilities. However a significant model has been prepared by Arup, as part of their work on the new Opera Hall upgrade (see later detail on this information).

3.6 Facilities Plan Room

The Plan Room has a very well managed microfilm store (~30,000 records), which has been thoroughly indexed. An extensive set of survey, original design and building services drawings are available, although they are predominantly design documents.

Recently the key parts of the microfilm archive have been converted to pdf format, and are available in a preliminary version on an intranet for all Sydney Opera House Facilities staff.

A comprehensive and developing set of documentation, building and related coding standards have been established (see BIMSS Report). This incorporates fire zones, room naming and door identification, etc.

A penetrations database (at firewalls etc.) is established to monitor the efficacy of fire zone protection.

3.7 Building Services

Electrical services were upgraded 10 years ago with little consideration of the services master planning, nor the original Utzon building planning and servicing concepts.

An automation project is in hand (for example, converting to C-BUS networks) that will address lighting control issues and strengthen the now much increased stage lighting and related automation systems throughout the building.

3.8 Security

A new security system has been installed that controls access to and monitors usage of the Sydney Opera House facilities.

3.9 Asset Strategy

Over the last 2 years the facilities portfolio has established a number of standards for particularly building services systems (where most maintenance and associated works occur).

3.10 Current Services Status

A number of key concerns are evident at Sydney Opera House:

- the building structure is complex, and building service systems - already the major cost of ongoing maintenance - are undergoing technology change, with new computer based services becoming increasingly important.
- the current “documentation” of the facility is comprised of several independent systems, some overlapping and is inadequate to service current and future services required
- the building has reached a milestone age in terms of the condition and maintainability of key public areas and service systems, functionality of spaces and longer term strategic management.
- many business functions such as space or event management require up-to-date information of the facility that are currently inadequately delivered, expensive and time consuming to update and deliver to customers.
- major building upgrades are being planned that will put considerable strain on existing facilities portfolio services, and their capacity to manage them effectively

4. Building Information Models (BIM)

An important consideration in the context of the current dimensionally inaccurate 2D CAD data, and significant upgrade projects planned for Sydney Opera House over the next 5-10 years is the use of an integrated model of the building – otherwise called a Building Information Model to support in a comprehensive manner all the asset and facility management operations required by Sydney Opera House.

4.1 A Definition of BIM

BIM's represent an integrated digital description of a building and its site comprising objects, described by accurate 3D geometry, with attributes that define the detail description of the building part or element, and relationships to other objects e.g. this duct *is-located-in* storey three of the building named Block B.

BIM is called a *rich* model because all objects in it have properties and relationships, and based on this useful information can be derived by simulations or calculations using the model data. An example is the ability to perform automated code checking to confirm egress, fire ratings etc. or a thermal load calculation.

The principal difference between BIM and 2D CAD is that the latter describes a building by independent 2D views (drawings), e.g. plans, sections and elevations. Editing one of these views requires that all other views must be checked and updated if necessary, a clumsy and error prone process that is one of the major causes of poor documentation today. In addition, the data in these 2D drawings are graphical entities only, e.g. line, arc circle, etc. in contrast to the intelligent semantic of BIM models, where objects are defined in the terms of building parts and systems eg. spaces, walls[1], beams, piles etc.

4.2 Generic Attributes of BIM

The key generic attributes are:

- *robust* geometry - objects are described by faithful and accurate geometry, that is measurable
- *comprehensive and extensible object properties* that expand the meaning of the object - any object in the model has some pre-defined properties or the IFC specification allows for any number of user or project specific properties according to a common format. Objects thus can be richly described e.g. a manufacturers' product code, or cost, or date of last service etc.
- *semantic richness* - the model provides for many types of relationships that can be accessed for analysis and simulation e.g. is-contained-in, is-related-to, is-part-of etc.
- *integrated information* - the model holds all information in a single repository ensuring consistency, accuracy and accessibility of data
- *life cycle support* - the model definition supports data over the complete facility life cycle from conception to demolition, extending our current over-emphasis on design and construction phase. For example client requirements data such as room areas or environmental performance can be compared with as-designed, as-built or as-performing data, a vital function for AM / FM.

[1] Technically a wall in an IFC model is called *ifcWall* etc.

4.3 BIM Benefits

The key benefit of BIM is its accurate geometrical representation of the parts of a building in an integrated data environment.

Related benefits are:

- *Faster and more effective* processes – information is more easily shared, can be value-added and reused
- *Better design* – building proposals can be rigorously analysed, simulations can be performed quickly and performance benchmarked enabling improved and innovative solutions
- *Controlled whole life costs and environmental data* - environmental performance is more predictable, life-cycle costs are understood
- *Better production quality* – documentation output is flexible and exploits automation
- *Automated assembly* – digital product data can be exploited in downstream processes & manufacturing
- *Better customer service* – proposals are understood through accurate visualisation
- *Life-cycle data* – requirements, design, construction and operational information can be utilised in FM.
- *Integration of planning and implementation* processes – government, industry and manufacturers have a common data protocol
- More effective and competitive industry

4.4 Interoperability or Building Data Sharing

Interoperability is defined as the seamless sharing of building data between multiple applications (or disciplines) over any or all life cycle phases of a building development project. Although BIM may be considered as an independent concept, in practice, the business benefits of BIM are dependent on the shared utilisation and value-added creation of integrated model data.

To access model data therefore requires an *information protocol*, and although several vendors have their own proprietary database formats, the only open global standard is that published by the International Alliance for Interoperability (IAI) called IFC.

4.5 IFC Protocol

The IAI is a worldwide alliance of organisations in the construction industry - Architecture, Engineering, Construction and Facilities Management (AEC/FM) - comprising 12 international chapters, from 21 countries with representation by over 550 businesses from private industry and government.

The IAI's stimulus in developing the IFC protocol was the recognition that the greatest problem in the construction industry today is the management of information about the built environment. Although every other business sector has embraced IT and adopted industry specific standards, the Construction Industry - indeed worldwide – has stuck to its trade based roots and dependence on drawings, with a continuing record of poor quality, low investment value and poor financial rewards.

4.6 Data Sharing with BIM

The mission of the IAI is to integrate the AEC/FM industry by specifying a universal language that improves communication, productivity, delivery time, cost, and quality throughout the design, construction, operation and maintenance life cycle of buildings.
The focus on life-cycle has been a key aspect, as the current industry practice does not facilitate the efficient transfer of requirements, design and as-built construction data for the increasingly critical phases of operations and strategic AM / FM.

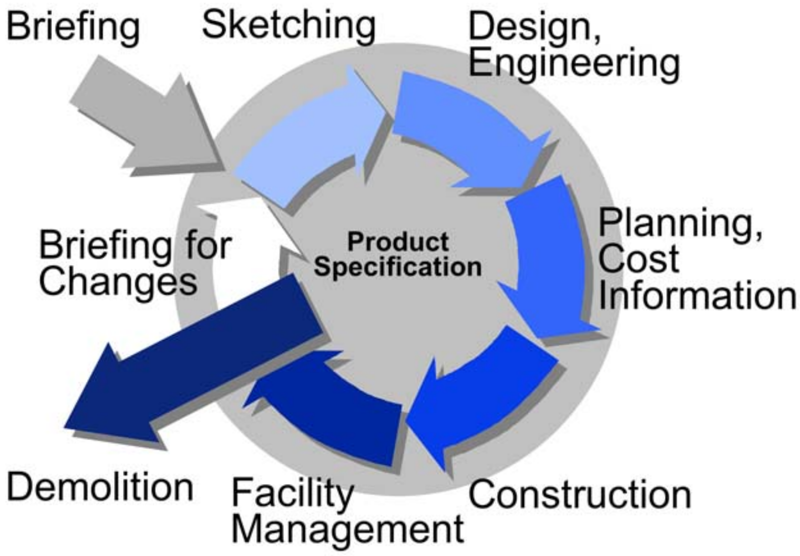


Figure 2: Information Lifecycle, Arto Kiviniemi, VTT

The focus on life-cycle has been a key aspect, as the current industry practice does not facilitate the efficient transfer of requirements, design and as-built construction data for the increasingly critical phases of operations and strategic AM / FM.

In the discussion which follows we emphasise that building models and open interoperability are necessary complements of each other. Without the IFC sharing standard, data cannot be accessed in an industry open format; similarly, use of IFC requires integrated model data and cannot work with 2D drawings.

4.7 Initial Developments

The standard, which has undergone several releases since the first commercially supported version IFC 1.5.1 in 1999, commenced – principally in northern Europe - with the major (so called *upstream*) CAD vendors implementing IFC support. This development demonstrated the feasibility of modelling the building geometry (or shell) and as such largely covered the architectural layout of a building.

4.8 Building as a System

From 2000-2003 the model was extended in two important respects: first definition of a stable platform within the standard, a core to encourage more vendors to support the protocol by ensuring the initial investment software development had a secure future. The second, more directly important for users, was support for engineering systems, structures – concrete, steel timber and pre-cast, and building services – HVAC, electrical, hydraulic, fire etc.

The combination of these developments now underpinned a wide number of typical business case processes, and thus attained a level of functional maturity enabling IFC to be adopted as an ISO standard (ISO/PAS 16739) in 2002, the first such comprehensive information standard for building in the world.

The recent extension of the model for GIS data has provided a reliable link between the building and the planning professions, enabling public authorities and government to manage and to innovate services based on comprehensive, reliable information databases of assets / facilities / buildings and their land/urban context - the Built Environment.

5. Industry Take-up of Building Information Models

5.1 Finland

World leader in model based construction services

With the steady improvement of IFC came several new vendors - *downstream* applications for building and engineering services, allowing in Finland a definitive case study, under the sponsorship of Government through its Technology agency Tekes, pro-actively promoting model based construction services. The Helsinki University of Technology Auditorium project originally designed by Alvar Aalto, was undertaken by the owner of University facilities in Finland, Senate Properties to test the benefits of IFC based collaboration. The project was independently reviewed by the Centre for Integrated Facilities Engineering at Stanford, US. Their PM4D Final Report, (CIFE Technical Report 143 - see http://www.stanford.edu/group/4D/download/c1.html) documented the pros and cons of this BIM/IFC based project. Senate Properties' ambitions were not completely met, but the CIFE evaluation clearly showed that substantial benefits were achieved where IFC collaboration was successful; the report not only identified positive issues, it also examined why communication failed and how this might be improved. The assessment covers the priorities of the many participants and from the client's perspective the project made enormous progress in showing the benefits based on this new process and data sharing protocol.

Importantly the review confirmed the strategic benefits of this approach for industry.

Auli Karjalainen, Customer Manager at Senate Properties confirmed the organisation's continuing commitment to model based facility development. (see http://www.stanford.edu/group/CIFE/FinSoftwareDay/Presentations/SenateFSDatCIFE.pdf?siteID=2): "Working as a team with Product Models in Virtual Reality will result in a better quality of process and product, better solutions of spaces for the client, opportunities to change functions in the future, better opportunities for making decisions during the process, especially in early phases of projects, client commitment and an effective process through networking"

Since 2002 many pilots and projects have been undertaken in Finland, Sweden, Norway, Germany, France, Singapore, UK and Australia, which have demonstrated the capability of the IFC model to represent data and processes with in the AEC/FM domain accurately and efficiently.

5.2 Singapore

Innovation in building code checking

The Building Construction Authority of Singapore – a member of the IAI – had been developing an automated code checking service since the early 1990's with limited success using then current 2D drawing CAD software, and realised in 2000 that IFC offered a definitive technology for the proposed system. In 2003 it released its first operational automated code checker accessed through a single web portal and newly integrated administration of some 13 agencies responsible for building assessment and regulatory approval. The ePlanCheck system uses an expert system, based on an IFC model server, to interpret and check a building proposal submitted to it in IFC file format. The Singapore development system uses the new IFC 2x2 functionality and following certification of a supporting CAD system (ArchiCAD) and the ePlanCheck system itself, has released it to the Singapore industry for use.

ePlanCheck has generated a lot of international attention – the automation, reuse of intelligent data, and time saving alone showed dramatic new potential; the IFC model data not only could be used as a better environment for multi-disciplinary design, it also was shared for building assessment and could act as reference data for local government and other government agency uses. Notably the rich data could be used for AM / FM if during the construction process as-built information was updated in the model.

5.3 Norway

Leveraging ePlanCheck through GIS

The Norwegian government visited Singapore in late 2003, and were impressed by the system. An MOU was established between the two countries allowing Norway to use ePlanCheck technology and the national building agency Statsbygg undertook the development of a Development Approval System - Byggsøk. While this shared a similar structure as the Singapore system, it needed land and planning information that was not yet supported by the IFC standard. Accordingly Norway, with comprehensive geographic information systems in place, lead a project to bridge this gap and in May 2005 another significant turning point for IFC and BIM was the release of a new version of the IFC standard that supports integration with GIS data.

Norway accomplished this in just over 13 months, demonstration of the rapidly improving base technology, expanding application support and widening knowledge of BIM and IFC. Implementation by the government agencies in Singapore and Norway with automated building regulation checking and development zoning approval systems respectively are underpinning innovative and much more efficiently delivered services by local & national government agencies responsible for the certification and management of built development.

5.4 USA

General Services Administration (GSA) mandates IFC for capital works approval

The North American Chapter of the IAI is a founding partner and has played a dominant role in supporting the IFC effort.

Statistics released by the US Department of Commerce show that in four decades, from 1964 to 2004, productivity in the construction industry has actually declined while in all other non-agricultural industries productivity is up 30%. An August 2004 Report by NIST[2] entitled "Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry" quantified the annual costs to the capital facilities industry, of $15.8 billion which represents between 1-2% of the industry's revenue.

'Starting in October[3], when fiscal year 2006 begins, all AEC firms dealing with the General Services Administration will have to include a BIM as part of their work proposal. Stephen Hagan, who heads GSA's Project Knowledge Centre… threw out his challenge to the construction industry by saying that his organisation is not looking for new a technology, but rather for an efficient way to solve a serious business problem. GSA has $12 billion in active projects. "Too many are not on time and not on budget,"

[2] See NIST website http://www.bfrl.nist.gov/oae/publications/gcrs/04867.pdf

[3] See Engineering News Record article http://enr.com/print.asp?REF=http://enr.com/news/informationtech/archives/050121.asp

The real value of BIM, says contractor Jim Bedrick, director of systems integration at Webcor Builders, is the ability to collaborate between architect, builder and major subcontractors, leading to better value for the owner. He sees the BIM model as having long term implications for the owner's ability to operate and maintain the facility after the construction hand-off. Detailed modelling gives the owner easy access to critical building information.

Hagan would like to see the AEC community create added value for the owner by specifically building a BIM model just for operations and maintenance purposes.

Martin Fischer, director of Stanford University's Centre for Integrated Facility Engineering (CIFE) confirmed with hard data that utilising 3D and 4D modelling at the appropriate early stages in the design and construction process results in significant building efficiencies and cost savings. For example, he cited in one project, "usable square footage increased 20% in the same building footprint because of better modelling'.

6. Facility Management (FM) Support in IFC

The capacity for whole facility life cycle management has been a central concept in the IFC model specification (see Figure 2 above). The core model is a rich description of the building elements and engineering systems that provides an *integrated* description for a building. This feature together with its geometry (for calculation and visualisation), relationships and property capabilities underpins its use as an AM / FM database.

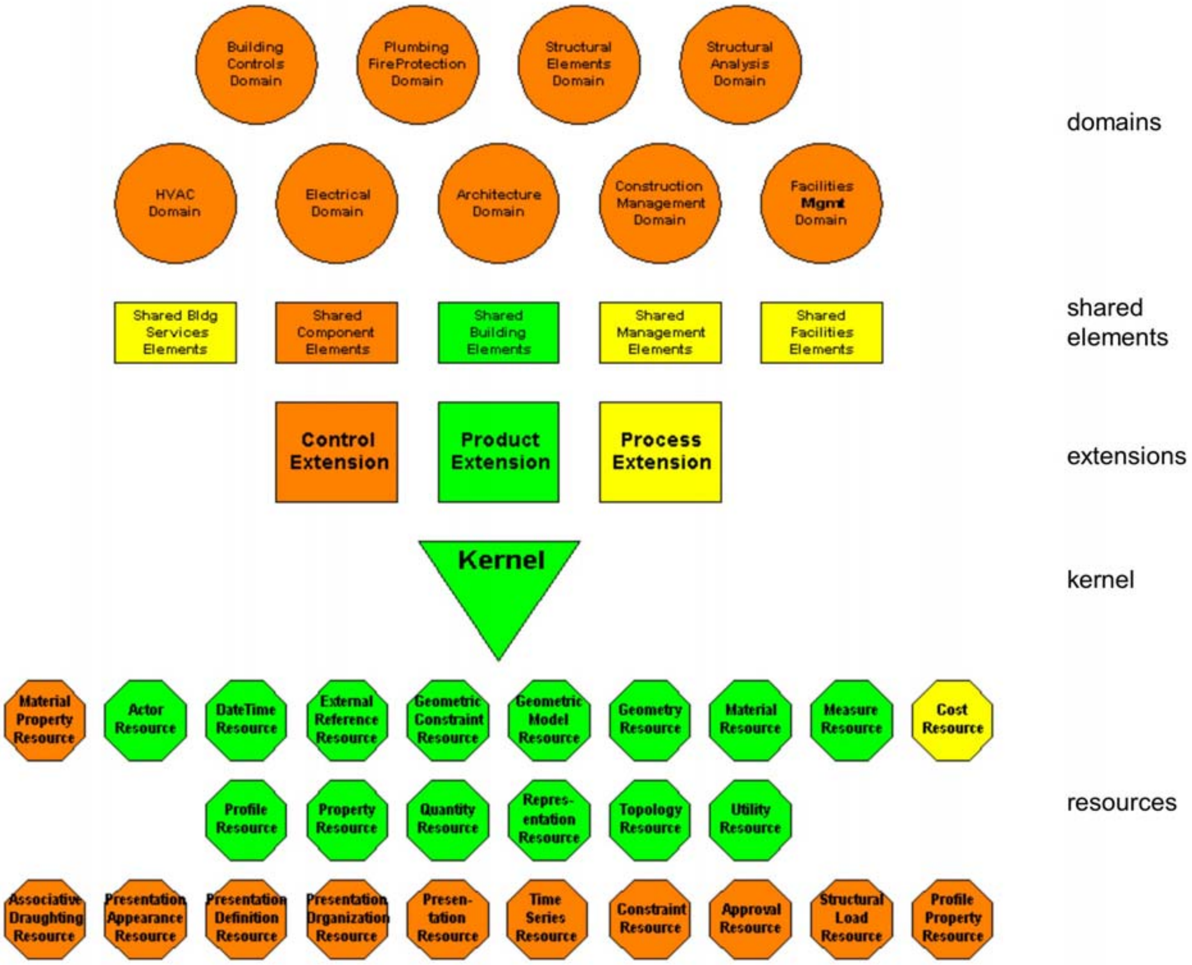


Figure 3: IFC 2x series Model, Model Support Group, IAI

However, the model from its first release has supported many other concepts needed for operational AM / FM. Referring to Figure 3 above, the model is represented as follows:

- *resources* – fundamental concepts, generally taken from the STEP standard[4]
- *the kernel* – concepts used globally in the model
- *extensions* – specialisation of resources needed uniquely for AEC/FM domains
- *shared elements* – common concepts used by domains
- *domains* – functionally independent views (or disciplines) of the AEC/FM model

The model specialises data for use in various domains eg Architecture, HVAC and for our purposes FM.

[4] ISO 10303 STEP - **Standard for the Exchange of Product Data** is the parent standard of IFC, and encompasses support for the manufacturing sectors of Shipbuilding, Process Plant, Offshore and Building & Construction,

6.1 Some Key Concepts of the IFC Model[5]

Before describing in detail the more specific concepts that may apply to FM a number of general IFC concepts (called "kernel" in the IFC specification) will help to set the context.

IfcProject The undertaking of some design, engineering, construction, or maintenance activities leading towards a product. The project establishes the context for information to be exchanged or shared, and it may represent a construction project but does not have to.

IfcActor defines all actors or human agents involved in a project during its full life cycle. It facilitates the use of person and organisation definitions in the resource part of the IFC object model.

IfcProduct Any object, or any aid to define, organise and annotate an object, that relates to a geometric or spatial context. Subtypes of *IfcProduct* usually hold a shape representation and a local placement within the project structure.

This includes manufactured, supplied or created objects (referred to as elements) for incorporation into an AEC/FM project. This also includes objects that are created indirectly by other products, as spaces are defined by bounding elements.

In addition to physical products (covered by the subtype *IfcElement*) and spatial items (covered by the subtype *IfcSpatialStructureElement*) the *IfcProduct* also includes non-physical items, that relate to a geometric or spatial contexts, such as grid, port, annotation, structural actions, etc.

IfcProcess An action taking place in building construction with the intent of designing, costing, acquiring, constructing, or maintaining products or other and similar tasks or procedures. Processes are placed in sequence (including overlapping for parallel tasks) in time, the relationship *IfcRelSequence* it used to capture the predecessors and successors of the process. Processes can have resources assigned to it, this is handled by the relationship *IfcRelAssignsToProcess*.

IfcPropertyDefinition defines the generalisation of all characteristics (i.e. a grouping of individual properties), that may be assigned to objects. Property definitions can be property set definitions, or type objects.

IfcRelationship The abstract generalisation of all objectified relationships in IFC. Objectified relationships are the preferred way to handle relationships among objects.

IfcRelAssociatesDocument This objectified relationship is used to assign a document reference or a more detailed document information to objects. A single document reference can be applied to multiple objects.

IfcRelAssociatesLibrary This objectified relationship (*IfcRelAssociatesLibrary*) handles the assignment of a library item (items of the select *IfcLibrarySelect*) to objects (subtypes of *IfcObject*).

[5] The following specification is extracted from the IFC Model Specification (see http://www.iai-international.org/Model/files/20040721_IfcR2x2_Add1_html_distribution.zip)

The relationship is used to assign a library reference or a more detailed link to a library information to objects, property sets or types. A single library reference can be applied to multiple items.

IfcControl is the abstract generalisation of all concepts that control or constrain products or processes in general. It can be seen as a specification, regulation, cost schedule or other requirement applied to a product or process whose requirements and provisions must be fulfilled. Controls are assigned to products, processes, or other objects by using the *IfcRelAssignsToControl* relationship.

EXAMPLE: Controls are space brief, cost schedules, orders, work plan, etc.

IfcResource contains the information needed to represent the costs, schedule, and other impacts from the use of a thing in a process. It is not intended to use *IfcResource* to model the general properties of the things themselves, while an optional linkage from *IfcResource* to the things to be used can be specified (i.e. the relationship from subtypes of *IfcResource* to *IfcProduct* through the *IfcRelAssignsToResource* relationship).

For more examples of IFC element entities used in the description of Sydney Opera House, see the BIMSS Report

6.2 IfcSharedFacilitiesElements

The IfcSharedFacilitiesElements Schema defines basic concepts in the FM domain. This schema, along with *IfcProcessExtension, IfcSharedMgmtElements* and *IfcFacilitiesMgmtDomain*, provide a set of models that can be used by applications needing shared information concerning FM related issues.

The IfcSharedFacilitiesElements schema supports ideas including:

- Furniture.
- Grouping of elements of system furniture into individual furniture items.
- Asset identification.
- Inventory of objects (including asset, furniture and space objects within separate inventories).

Model entities within the IfcSharedFacilitiesElements domain are:

IfcActionRequest is a request for an action to fulfil a need.

IfcCondition determines the state or condition of an element at a particular point in time

IfcConditionCriterion is a particular measured or assessed criterion that contributes to the overall condition of an artifact.

IfcEquipmentStandard is a standard for equipment allocation that can be assigned to persons within an organisation.

IfcFurnitureStandard is a standard for furniture allocation that can be assigned to persons within an organisation.

IfcMove is an activity that moves people, groups within an organisation or complete organisations together with their associated furniture and equipment from one place to another. The objects to be moved, normally people, equipment, and furniture, are assigned by the *IfcRelAssignsToProcess* relationship.

IfcOrderAction is the point at which requests for work are received and processed within an organisation.

IfcPermit A document that allows permission to carry out actions in places and on artifacts where security or other access restrictions apply.

6.3 IfcFacilitiesMgmtDomain

The *IfcFacilitiesMgmtDomain* Schema defines basic concepts in the FM domain.

The *IfcFacilitiesMgmtDomain* schema forms part of the Domain Layer of the IFC Model. It extends the ideas concerning FM outlined in the *IfcSharedFacilitiesElements* schema and management in general outlined in the *IfcSharedMgmtElements* schema. The objective is to capture information that supports specific business processes that are wholly within the domain of interest of the Facilities Manager. The aim is to provide support for information exchange and sharing within computer aided facilities management (CAFM) and computer aided maintenance management applications. The model extent will not support some of the more detailed ideas found in these applications.

The following are within the scope of this part of the specifications:

- Managing the movement of people and their associated equipment from one place to another. All types of move are considered to be within scope ranging from moving a single person from one office to another to the movement of complete organisations between locations.
- The assignment of FM standards according to roles played by actors within an organisation. Assignment of standards is limited to space, furniture and equipment.
- Capturing information concerning the condition of components and assets both for subjective and objective assessment of condition.
- Recording the assignment of permits for access and carrying out work.
- Capturing requests for action to be carried out and the assignment of work orders to fulfil the needs expressed by requests.

The following are outside of the scope of this part of the specifications:

- Work interactions between actors and between space programs.
- Moving or identifying the movement of or identifying the need for (as a result of moving) electrical or telecommunications services or connection points or the need for new electrical or telecommunications equipment as a result of the move.
- FM standards other than space, furniture and equipment.

Model entities within the IfcFacilitiesMgmtDomain domain are:

IfcAsset is a uniquely identifiable grouping of elements acting as a single entity that has a financial value

IfcFurnitureType defines a particular type of item of furniture such as a table, desk, chair, filing cabinet etc.

IfcInventory is a list of items within an enterprise

IfcOccupant is a type of actor that defines the form of occupancy of a property.

IfcRelOccupiesSpaces is a relationship class that further constrains the parent relationship *IfcRelAssignsToActor* to a relationship between occupants (*IfcOccupant*) and either a space (*IfcSpace*), a collection of spaces (*IfcZone*), a building storey (*IfcBuildingStorey*), or a building (*IfcBuilding*).

IfcServiceLife is the period of time that an artefact (typically a product or asset) will last.

IfcServiceLifeFactor captures the various factors that impact upon the expected service life of an artifact.

IfcSystemFurnitureElementType defines a particular type of component or element of systems or modular furniture.

6.4 IfcSharedMgmtElements

The *IfcSharedMgmtElements* schema defines basic concepts that are common to management throughout the various stages of the building lifecycle. The primary classes in the schema are all subtypes of *IfcControl* and act to manage or regulate the conduct of the project in some way. This schema, along with *IfcProcessExtension* and *IfcConstructionMgmtDomain*, provide a set of models that can be used by applications needing to share information concerning management related issues.

The objective of the IfcSharedMgmtElements schema is to capture information that supports the ordering of work and components, the development of cost schedules and the association of environmental impact information. The aim is to provide support for exchange and sharing of minimal information concerning the subjects in scope; the extent of the model will not support the more detailed ideas found in more specialised management applications.

The following are within the scope of this part of the specifications:

- Principal types of order that may be used in the project and whose details need to be captured for the project including purchase orders, change orders and work orders.
- Schedules of costs.
- Association of cost and environmental impact of information to specific objects as required.

The following are outside of the scope of this part of the specifications:

- Transaction details that may be supported by or support electronic commerce.

Model entities within the IfcSharedMgmtElements domain are:

IfcCostItem describes a cost or financial value together with descriptive information that describes its context in a form that enables it to be used within a cost schedule.

IfcCostSchedule brings together instances of *IfcCostItem* either for the purpose of identifying purely cost information as in an estimate for constructions costs, bill of quantities etc. or for including cost information within another presentation form such as an order (of whatever type)

IfcProjectOrder sets common properties for project orders issued in a construction or FM project.

IfcProjectOrderRecord records information in sequence about the incidence of each order that is connected with one or a set of objects.

IfcRelAssignsToProjectOrder is a relationship class that captures the incidence of a project order for a set of objects and whose occurrences can be recorded within a project record in sequence as a series of events.

IfcRelAssociatesAppliedValue enables the association of an instance of IfcAppliedValue with one or more instances of *IfcObject*.

IfcRelSchedulesCostItems is a subtype of *IfcRelAssignsToControl* that enables one or many instances of *IfcCostItem* to be assigned to an instance of *IfcCostSchedule*.

6.5 IfcProcessExtension

The *IfcProcessExtension* schema provides the primary information that expands one of the key ideas of the IFC Model. This is the idea of 'process' which captures ideas about the planning and scheduling of work and the tasks and procedures required for its completion. It is important to understand that process information can be expressed by classes in exactly the same way as product information. A process can also have state and identity, the state being determined by the values of various attributes of the processes.

The *IfcProcessExtension* schema extends the primary idea of the *IfcProcess* outlined in the *IfcKernel* schema. The objective of the *IfcProcessExtension* schema is to capture information that supports the planning and scheduling of work and the procedures and resources required to carry out work. The aim is to provide support for information exchange and sharing within commonly used scheduling applications; the extent of the model will not support the more detailed ideas found in more specialised scheduling applications.

The following are within the scope of this part of the specifications:

- definition of work plans including the tasks that are included within the plan and identification of the resources required by the plan,
- definition of work schedules together with the elements that make up the schedule, the time constraints and durations applicable to the elements,
- identification of work tasks included in plans and schedules,
- identification of procedures that are considered to not consume time in their accomplishment,
- identification of the relationship between a process and the resources that are consumed by the process,
- allocation of resources to work plans, work schedules and work tasks.

Model entities within the *IfcProcessExtension* domain are:

IfcProcedure is an identifiable step to be taken within a process that is considered to occur over zero or a non-measurable period of time.

IfcRelAssignsTasks is a relationship class that assigns an *IfcTask* to an *IfcWorkControl*. The assignment is further qualified by attaching an *IfcScheduleTimeControl* to the assignment to give the time constraints of the work task, when assigned to a work plan or schedule.

IfcScheduleTimeControl captures the time-related information about a process including the different types (i.e. actual, or scheduled) of starting and ending times, duration, float times, etc.

IfcTask is an identifiable unit of work to be carried out independently of any other units of work in a construction project.

IfcWorkControl is an abstract supertype which captures information that is common to both *IfcWorkPlan* and *IfcWorkSchedule*

IfcWorkPlan represents work plans in a construction or an FM project.

IfcWorkSchedule represents a task schedule in a work plan, which in turn can contain a set of schedules for different purposes.

6.6 Strategic Asset Planning and Facilities Management (FM)

The features above demonstrate the comprehensive model functions for asset and facilities planning. In summary BIM/IFC supports:

- Integrated FM
- Common operational picture for current and strategic planning
- Visual decision-making
- Open, universal standards
- Automated code and performance checks
- Total ownership cost model
- Energy simulations, performance
- Physical security (CBR, sick building)
- Intelligent 4D simulations
- Construction management

7. IFC Compliant Software for FM

A number of IFC based applications exist internationally (and one locally) for FM applications.

7.1 Vizelia, FR

This product has been written from scratch based on the IFC standard, initially for one of France's largest insurance companies AXA, for local and international offices' FM. Recently the product has been installed for the Municipality of Luxembourg. The application has strong space management functions.

7.2 RYHTI, FI

FM decision making processes require efficient management of information. Up to date information is essential both for strategic planning and leadership. It is also crucial for the management of facility services, for ensuring building functionality and for the monitoring of building performance.

To ensure this, a tool that enables measurement, monitoring and analysing of trends and following up targets is needed. When necessary, the tool must provide the possibility to drill into details.

RYHTI FM information management system

Systematic information is needed on all levels of operations, by top-level management, regional managers and service personnel as well as by service providers. The information must be easy to read and essential to the reader. In addition, the presentation of the information has to be adjustable to possible changes in operations and business models.

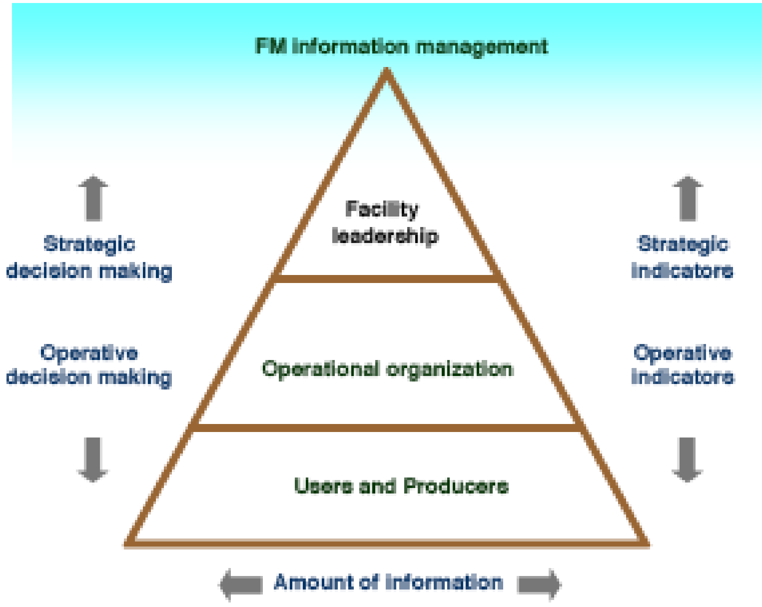


Figure 4a: RYHTI FM Interface

To meet these needs, Granlund has developed the RYHTI software for the management of buildings or entire building stocks. The RYHTI software has been developed in cooperation with leading real estate owners and maintenance organisations.

The RYHTI system is based on modules, enabling each organisation to choose the appropriate package for its needs and purposes. The package, which can easily be expanded at a later stage, fulfils the needs of the entire organisation and helps to allocate resources for the essential.

RYHTI is the tool to enable the organisation to develop operation models and to process data into information. Correct information is the basis for making the right decisions and reaching better results.

Data management

All modules of the RYHTI software run on a common database, which creates the basis for an efficient management of information. The database contains information on the facilities, technical systems, equipment, people and documents. Due to the open structure of the database, the system can easily be adjusted to the individual needs of different organisations.

Functions according to needs

The RYHTI software covers the technical management of facilities according to customer requirements. Because of its modular structure, the software can be expanded with changing needs.

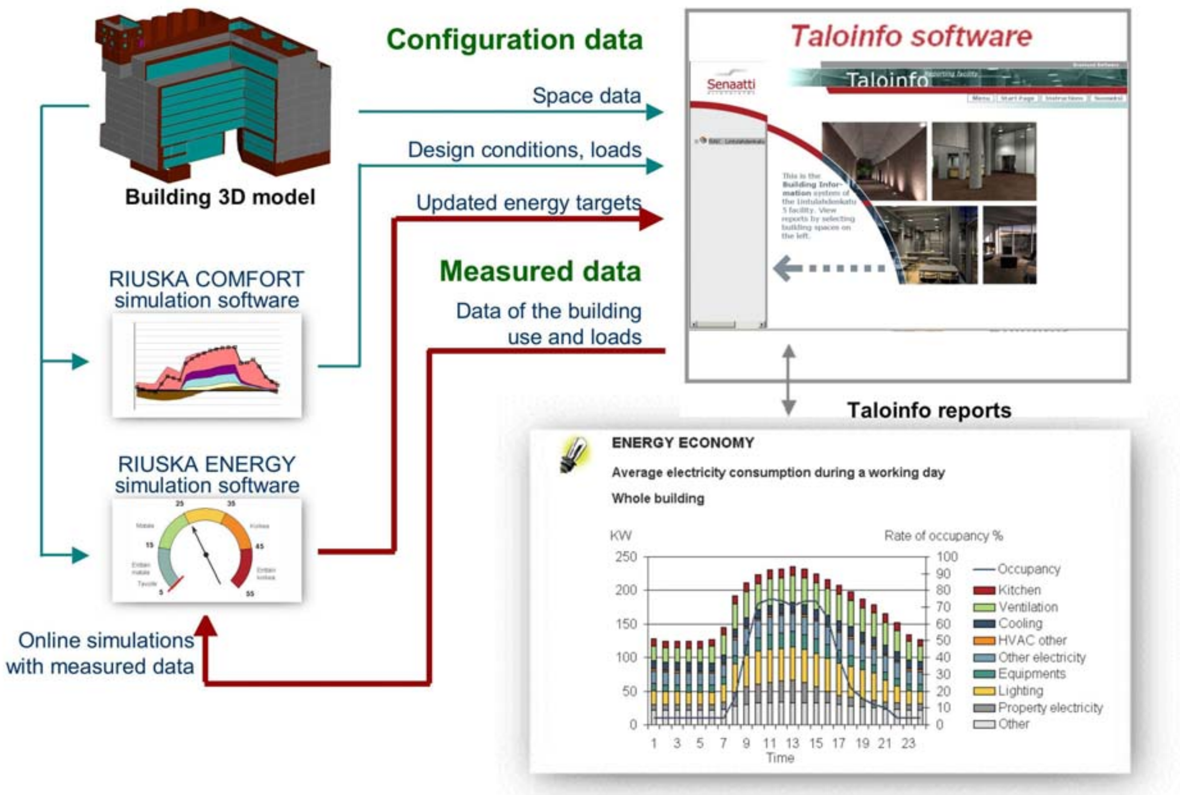


Figure 4b: Use of Product Models in Taloinfo System for Senate Properties, Finland, Olaf Granlund.

The following modules are available for the technical management of facilities:

- Maintenance, maintenance, planning and monitoring.
- Help Desk, request management and monitoring.

- LTP (Long Term Planning), planning and monitoring of long term maintenance and refurbishment.
- Contract, management of service contracts.
- Consumption, monitoring and reporting of energy and water consumption.
- Document, management and archiving of facility related drawings and other documents.
- Report, generation of reports fitted to the needs of the organisation.

User roles and operational environment

Most RYHTI functions are compatible both in PC OS and Web environments. The Web application makes the use of the information system efficient and easy. Access to the information in the system can be defined to fit the tasks and roles of each user.

Ryhti is used by over 300 clients, including Finland's Senate Properties, Nokia & Pfizer UK.

7.3 Rambyg, DK

This application has been developed in Denmark, by one of the country's largest multi-disciplinary engineering practices Rambøll. Their primary clients are Estate owners (councils etc).

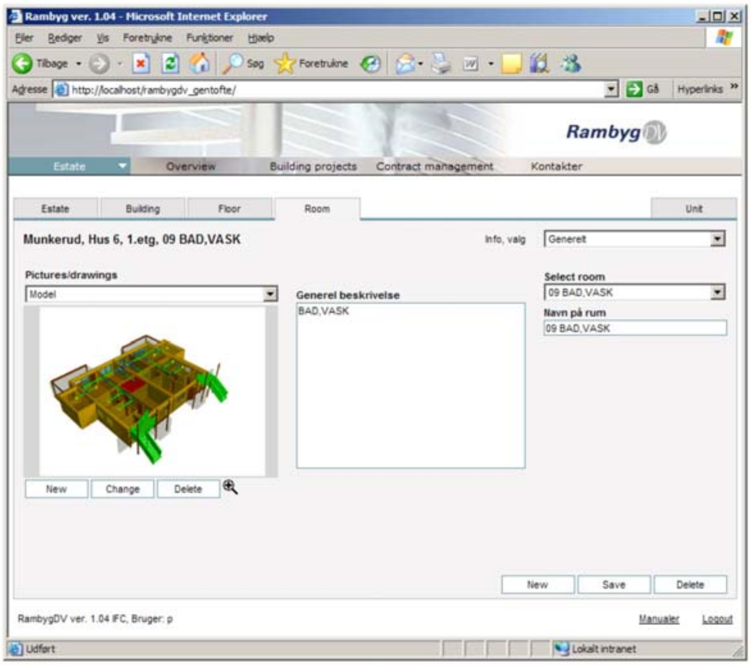


Figure 5: Rambyg FM Interface

Rambyg is a system for operation and maintenance of buildings. It is meant to be used throughout the facility life cycle. The system is web-based – all data is in one place and access to all data from any place with an internet connection. All the different actors use the system directly. Data is put into the system close to the source and those who need data get it directly from the system.

The system is a standard system which has been sold for 4 years

The import of IFC-files is a prototype, converting a traditional relational database and 2D documents solution. IFC compatibility was recently added using a Japanese model server tool IMSvr. This was a very rapid development which has provided a new way for accessibility to rich data.

7.4 ActiveFacility, AU

A Queensland based firm has developed an IFC server solution implemented in an Oracle database. ActiveFacility has created a new way of managing building data. This standard model stores, updates and provides ready access to the massive amount of information that relates to a building.

ActiveFacility's services and software systems are built on the ISO - endorsed IFC standards and are progressive tools for managing building information throughout the lifecycle of a building.

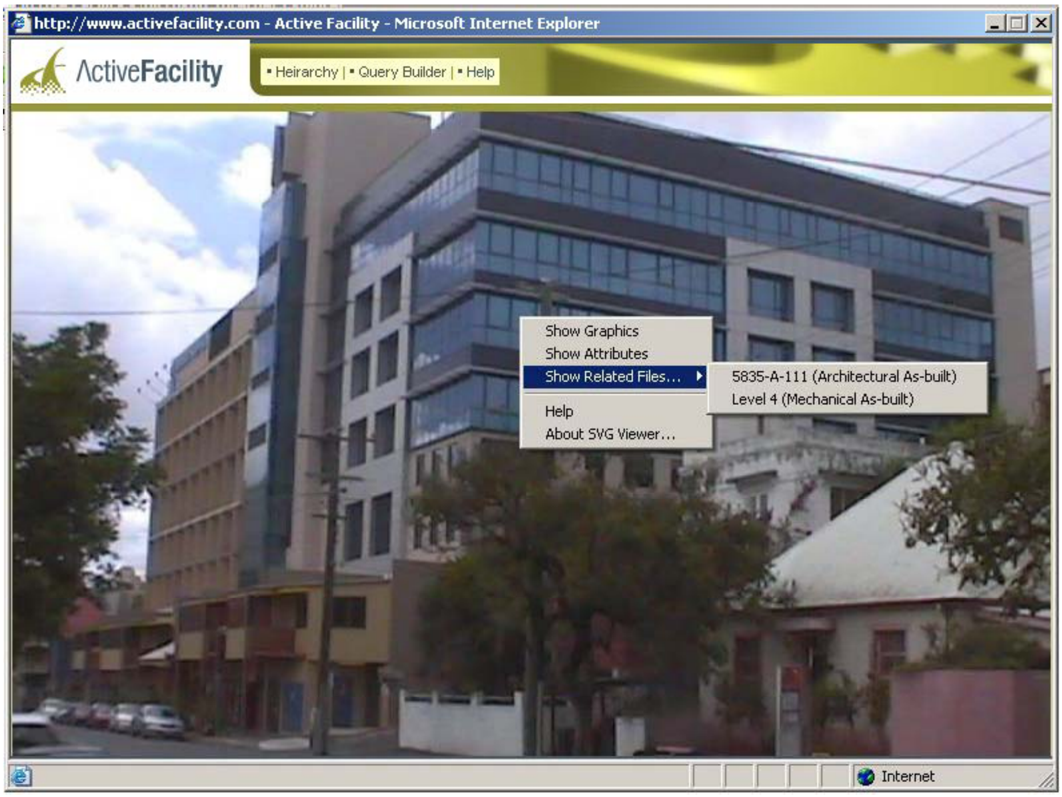


Figure 6: ActiveFacility System

Key features of the product[6] are:

- Creating an industry standard building model that encompasses all the information (architectural, mechanical, electrical, etc.) for an existing building.
- Making the unified building model accessible through the Internet so the information can be shared, analysed, queried and updated.
- Integrating the building model with other existing operational systems so all systems are continuously up-to-date.

A typical business issue: How do you answer everyday questions being asked of you, about your facility? Some typical examples could include:

- Where does this wire go?
- What is connected to the wire?
- Who will be affected if I cut this wire?

[6] ActiveFacility White Paper, 2 November 2004

- What is the area of a certain flooring material used throughout the complex of buildings?
- What services run through the ceiling space over a particular room?

These questions, while superficially trivial are, in reality, complex queries that can span multiple documents or drawings with a low degree of confidence that the source information is accurate, current, or available. Industry research suggests that up to 80% of a Facility Manager's time is spent finding information about the buildings they are managing. So how can a system be developed to assist in the management of this data, provide access to the data, and develop tools and processes to keep the data up to date?

ActiveFacility's mission is to provide solutions that answer these questions.

With a complete set of documentation and data, the ActiveFacility team begins the process of building a Unified Building Model. This is a manual process that consists of identifying building objects in the document sets and constructing a complete set of data about that object. Tools allow definition of users, reporting etc.

ActiveFacility supports Business Processes and workflows.

7.5 Server Developments – the SABLE Project[7]

SABLE - Simple Access to the Building Lifecycle Exchange – aims to replace file based data exchange by speeding up the use of Model Servers in the building industry. The SABLE project is being managed in Finland by EuroSTEP and is supported by the IAI, BLIS, the Finnish Government and a group of international software client groups and vendors.

It proposes to facilitate this through the creation of an abstraction of the data model defining *AEC Simple Interfaces or application programming interfaces (APIs)* to the data model instead of using it directly.

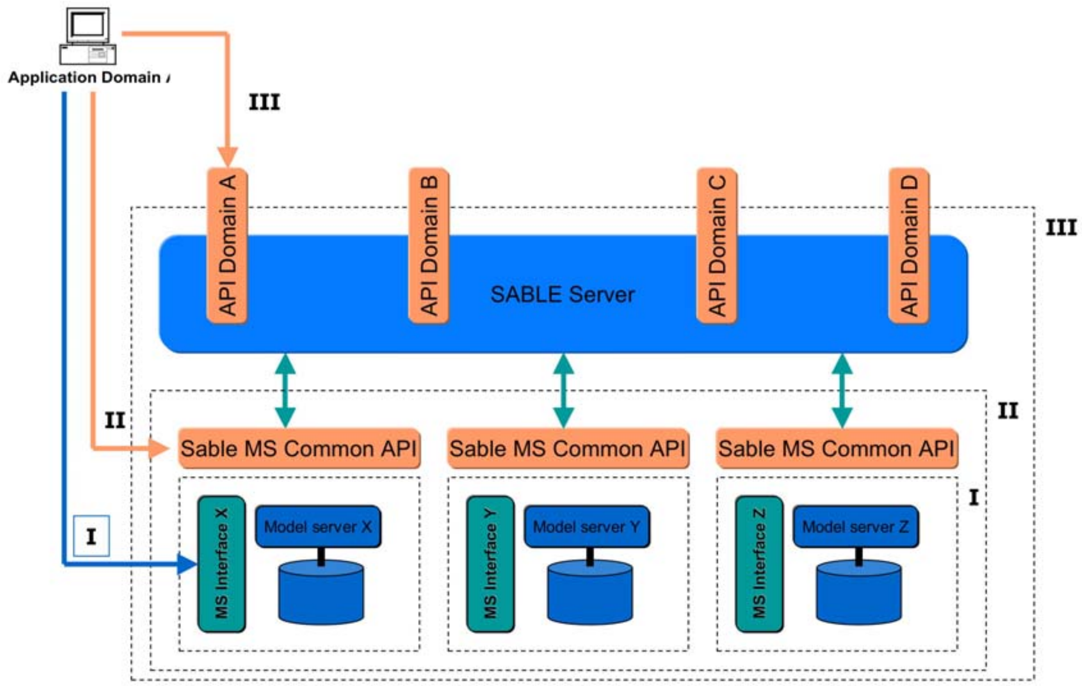


Figure 7: SABLE Model Server API Architecture, P Houbaux, EuroSTEP, Finland

This server approach

- Hides the complexity of the IFC data model by providing direct access to the needed data
- Minimises the dependency on the IFC Model version to allow the AEC/FM application vendors to make their implementation compatible with future releases of the IFC model
- Proposes a unified and standard way to access model servers by unifying both the partial model exchange format and the interface for developers.

The SABLE interfaces are currently under development; three levels of implementation are possible: through the API domain API, the SABLE Common MS API or direct to the Model Server interface. These are likely to become available during 2006 and further.

An example of the evolving FM API development is described in detail in Appendix B: SABLE FMIM API

[7] Simple Access to the Building Lifecycle Exchange (see http://www.blis-project.org/~sable)

The advantage of this work is that the use of APIs in the FM sector will greatly assist Australian and other developers develop more quickly IFC compliance and exploit the benefits of the BIM integrated data repository.

7.6 International FM Project – Ifc-mBomb[8]

***Note**: This description of the project is taken from the* Life-Cycle Data for Buildings: Opportunities of the IFC Model Based Operation and Maintenance *report, IAI UK, April 2005*

This project, funded by the UK Department of Trade and Industry, was carried out in the UK, completing in late 2004 and publishing its full results in 2005. The project leader was Taylor Woodrow, one of Britain's largest construction companies with a considerable portfolio of AM and members of the IAI UK Chapter.

Ifc-mBomb's starting premise was this: "The efficient operation and facilities management of a building relies on accurate, high quality information about the building itself. In practice, this transition is often stuttering and disjointed. Instead of a seamless reuse of the data, there is a manual re-inputting... The weakest information interfaces involve building services and facilities management." All in all, there is scope for error and omission, leading to problems in the operation and maintenance of the building later in its life cycle.

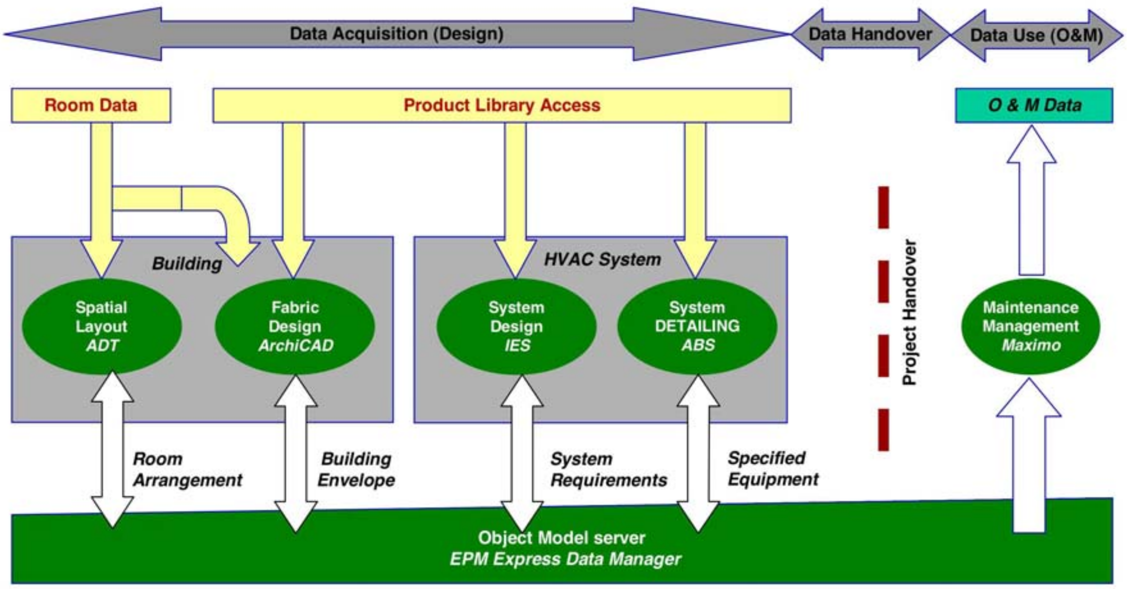


Figure 8: Ifc-mBomb Project concept, D Leonard & J Stephens, Taylor Woodrow, UK.

An end-user scenario was proposed at the start of the project. The aim was:

- To take room data sheet information created by the client and architect and to populate a FM system with the room requirements data
- To add information to the building model as the design team developed the building design. The scenario focused on the design and detailing of the building services required for the auditorium, which was situated in the centre of the building and spanned two storeys
- To perform iterations to the building services design and detailing using a number of software applications sharing the same common building model
- To generate O&M manual information from the building model.

[8] see http://cig.bre.co.uk/iai_uk/iai_projects/ifc-mbomb/

The project clearly demonstrated that using IFC model exchanges afforded more opportunities for end-users to select their preferred software application and still be able to exchange semantically rich data between systems. In many cases in the scenario, the choice of software used to create the building model was not important – as long as it was certified to support the IFC 2x specification.

Information was truly reused through the design, construction and FM phases of the project's life-cycle, as outlined below by a number of examples:

- Occupancy and temperature levels were used by energy analysis software
- Room numbers used all applications to identify spaces and their locations
- Heating and cooling requirements from the energy analysis application were used by the ductwork detailing software to size the ductwork components and fittings
- The building element materials and thicknesses were directly reused from the architectural building model by the energy analysis application
- Room requirements data sheet information was available in the FM system as first created early in the design stage
- Manufacturers' product data and recommendations were obtained from electronic catalogues and added to the model when elements were upgraded from generic to specific products
- Hazard and safety information was related to specific instances during design and included (in red) in the O&M documents.

The Ifc-mBomb project provides reliable evidence of the technical practicality and operational benefits that BIM based FM can achieve.

8. Building Information Specifications for Sydney Opera House

8.1 Introduction

The objective of this section is to use Sydney Opera House as a case study for the application of Building Information Modelling (BIM) for FM purposes. Sydney Opera House is a complex, large building with very irregular building configuration that makes it a challenging test.

A number of key concerns are evident at Sydney Opera House:

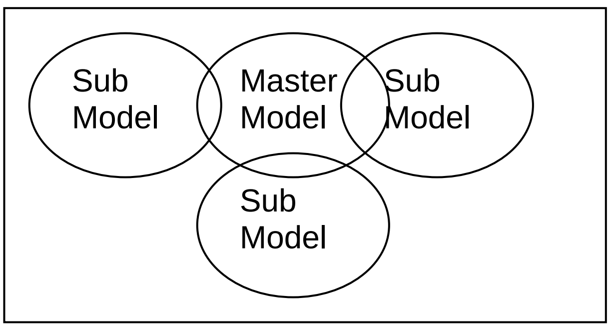
- the building structure is complex, and building service systems - already the major cost of ongoing maintenance - are undergoing technology change, with new computer based services becoming increasingly important.
- the current “documentation” of the facility is comprised of several independent systems, some overlapping and is inadequate to service current and future services required.
- the building has reached a milestone age in terms of the condition and maintainability of key public areas and service systems, functionality of spaces and longer term strategic management.
- many business functions such as space or event management require up-to-date information of the facility that are currently inadequately delivered, expensive and time consuming to update and deliver to customers.
- major building upgrades are being planned that will put considerable strain on existing Facilities Portfolio services, and their capacity to manage them effectively.
- While some of these concerns are unique to the House, many will be common to larger commercial and institutional portfolios.

The work described here supported a complementary task which sought to identify if a building information model – an integrated building database – could be created, that would support AM / FM functions.

8.2 Sydney Opera House Master Model Data

The FM Exemplar Project has sought to build up an accurate, reliable, and relevant integrated building model of Sydney Opera House complex to support operational management, building and service system alterations and additions and asset and maintenance management.

This is proposed to be achieved by progressive incremental development of a model using master and sub models, in accordance with operational, logistic and financial constraints. The Master Model for Sydney Opera House is divided into a number of logical discipline specific sub models.



Master model data shall only be sourced from Sydney Opera House with approval of the Technical Information Coordinator (TIC) at Sydney Opera House. No consultant or supplier shall use data provided to another party.

Note: Users must use a model (generally a partial model) sourced from Sydney Opera House. This is mandatory to ensure ifcEntity GUIDs (unique identifiers) are synchronised with the master model.

Where new model data is required to be created, this specification shall be used to determine the ifcEntity type, naming conventions and property data required.

Standard property sets (PSET) are defined for the IFC model and shall be used where applicable and in accordance with this specification. Custom PSETs may be used with the approval of the Sydney Opera House TIC.

Obtain the approval of the TIC before commencing work.

8.3 Sydney Opera House Sub-models

In order to manage an incremental development of building information model, sub models need administrative data so that changes and extensions to the master model can be tracked. A Sydney Opera House user of the Master Model shall obtain from the TIC a designation of their organisation's discipline and the organisation's authorised representative details (name and ID).

Discipline types are as follows:

Discipline	Identifier
Architecture	ARCH
Land Use	PLAN
Terrain	SURV
Cadastre	CADA
Utilities	UTIL
Structure	STRU
Mechanical	MECH
Electrical	ELEC
Communications	COMS
CAVS	CAVS
Security	SECU
Hydraulic	HYDR
Transportation	TRAN
Equipment	EQUI
Civil	CIVI
Roads	ROAD

If the contractor's role is not covered by the above Discipline types, obtain one from the TIC.

Contractors shall identify their organisation's details and designated representative in their IFC exports as follows:

IfcPerson

IFC Attribute	Setting
Id	Contractor Identifier issued by Sydney Opera House TIC
FamilyName	Family name of Contractor’s representative
GivenName	Given name of Contractor’s representative
MiddleName	OPTIONAL
PrefixTitles	OPTIONAL
SuffixTitles	OPTIONAL
Roles	Not applicable
Addresses	Not applicable

IfcOrganisation

IFC Attribute	Setting
Id	Discipline ID (as defined above) eg “MECH”
Name	Organisation name
Description	OPTIONAL
Roles	Not applicable
Addresses	OPTIONAL

Using these basic administrative labels, assertion of building information connected to the master model becomes traceable and consequently more manageable.

8.4 Sydney Opera House IFC Model Setup

IFC Data Requirement

Building model data shall comply with IFC (ISO/PAS 16739), release 2x Platform and subsequent extensions (2x2 etc) format, and in accordance with this Specification. Earlier release versions may be used only with the approval of the Sydney Opera House TIC and are generally not to be used.

File format may be in either Part 21 STEP physical file (SPF) ASCII (this is the default format); Part 28 XML (ifcXML) ASCII; or Part 22 SDAI STEP database access interface.

Note: Intending suppliers of IFC building model data should consult the Sydney Opera House Facilities Office to confirm the most appropriate data sharing process.

Software used to generate IFC data shall only be accepted from certified applications that can demonstrate they have been tested and comply with the appropriate IFC functionality (see the logo opposite of the two part certification for the Singapore Code Checking project).

Scale

All models shall be in metric scale 1:1, with units in millimetres to 0 decimal places.

Coordinate System

The Master Model for Sydney Opera House is based on a geographical reference grid defined as the "Sydney Opera House Plane Grid", and is being incorporated on all survey information at Sydney Opera House. This grid is based on a permanent survey mark of PM 61988, which has a MGA Easting of 334800.324 and a MGA Northing of 6252055.139. The bearing and distance of the principal azimuth between points PM 61988 and PM 59507 is 195°13’15” for a distance of 85.488 metres. The origin of levels is the State Survey Mark SSM 22994 which has a height of 4.458 on Australian Height Datum. The Sydney Opera HousePG is a local grid, rotated through an angle of 12°23’22” on the Sydney Opera House local grid point P1-01(the commemoration plaque on the Forecourt Stairs). This angle has been determined from a survey of selected tiles on the western forecourt area and may not be indicative of the entire site.

The Sydney Opera House has established a Survey Network (CCSN), comprising a set of Survey Marks throughout the site and buildings with reference to this datum.

All Model data shall be calibrated with these survey marks.

Project

The project shall be represented by the ifcProject entity.

ifcProject

IFC Attribute	Setting
Name	Sydney Opera House
Description	Sydney Opera House
Object type	Not applicable
Long name	Not applicable
Phase	TBC

Property Set usage is project and task dependent and shall be determined by Sydney Opera House.

Site

Sydney Opera House has facilities that are spread over several sites; the main site is at Bennelong Point, and remote facilities at the Rocks (Arts Exchange), CBD (Young Street) and Leichardt (Depot). The physical extent of the main site of the Master Model is available from the TIC. A Site shall be represented by the ifcSite entity. Note: Information about a site is represented by several disciplines: see section 3. The Site Model and GIS for the specialist disciplines involved.

ifcSite

IFC Attribute	Setting
Name	Eg “Bennelong Point”
Description	Land title description
Object type	Not applicable

Buildings

The Master Model is defined as the following building:

Sydney Opera House
The remote facility buildings are as follows:
Arts Exchange

Young Street Offices
Leichardt Depot

Buildings shall be represented by the ifcBuilding entity.

ifcBuilding

IFC Attribute	Setting
Name	eg “Sydney Opera House”
Description	Not applicable
Object type	Not applicable

Property Set usage is project and task dependent and shall be determined by Sydney Opera House.

Storey Settings

All storeys in the Bennelong Point buildings shall be named in accordance with the following table:

Note: The original documentation of the Sydney Opera House was in imperial units and the common name of the building storeys in use has been the height in feet above sea level eg “+03”. This code is the formal reference for storeys.

All units shall be in mm.

Table A.1: Bennelong Point Building Storeys

Level Code	Feet above Sea Level	Level Name	Elevation in metres
SB	-008	Sub-basement	-2.4384
BA	+001	Basement	0.3048
LC	+003	Lower Concourse	0.9144
GR	+012	Ground / Forecourt	3.6576
GM	+021	Ground mezzanine	6.4008
L1	+030	First Level, Green Room, Box Office	9.1440
L2	+042	Second Level - Podiums & Bars	12.8016
L3	+051	Third Level - Mural & ‘Caves’ Level	15.5448
L4	+061	Fourth Level – ‘Granite’ Level	18.5928
AG	+070	Auditoria - Gallery, Loges & Boxes	21.3360
RC	+090	Auditoria - Reflected Ceiling Level +90	27.4320
AC	+100	Auditoria - Ceiling Level +100	30.4800
AU	+115	Auditoria - Ceiling Upper Level +115	35.0520
AA	+130	Auditoria - Ceiling Above Level +130	39.6240
AS	+140	Auditoria - Under Concrete Shells	42.6720

Note: Building Storey definitions for remote facilities shall be obtained from the TIC.

ifcStorey

IFC Attribute	Setting
Name	*Feet above Sea Level* code as in Table A.1 above
Description	*LevelName* as in Table A.1 above (excepting levels VA and OH)
Object type	Not applicable
Long name	Not applicable
Complex type	Not applicable

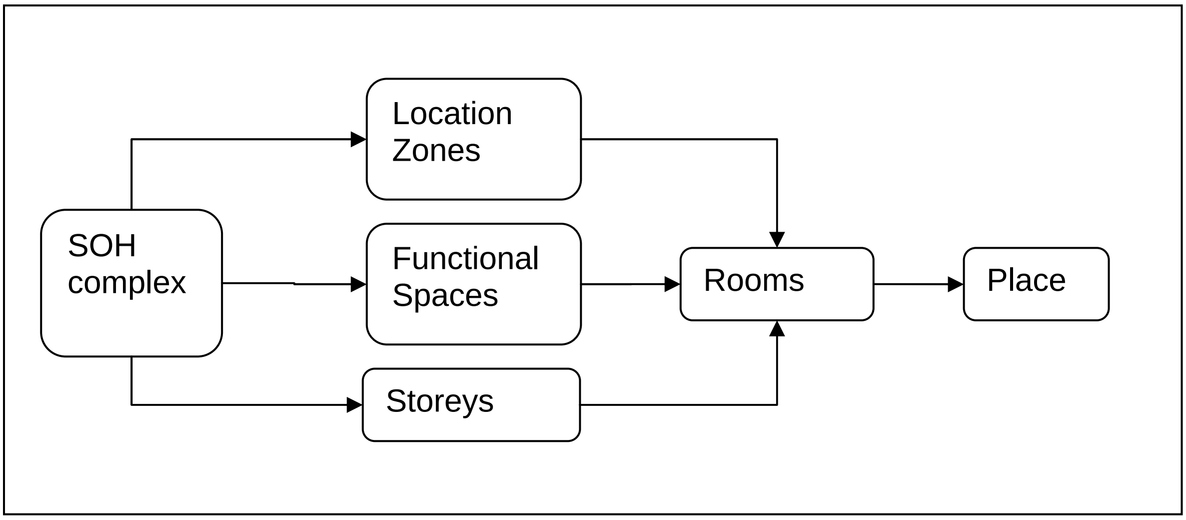
Property Set usage is project and task dependent and shall be determined by Sydney Opera House.

Spatial Hierarchy

The Master Model supports different spatial hierarchies based on the following entities:

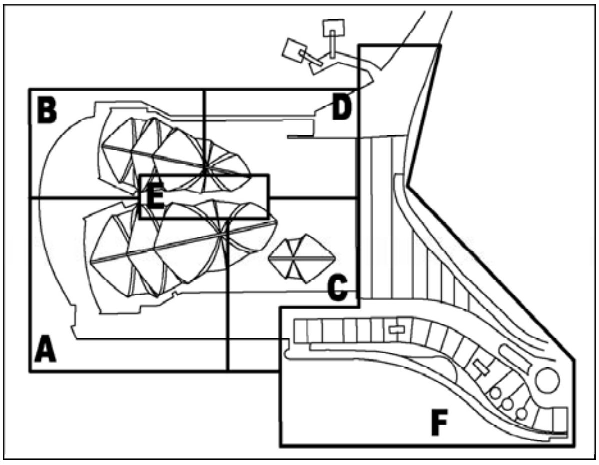
- Location Zones
- Functional Spaces
- Rooms
- Places

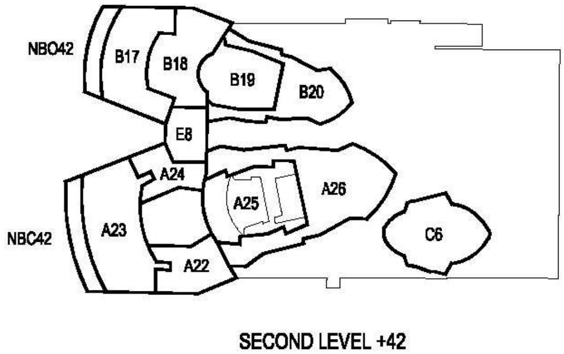
The following figure shows the relationships between the entities.



Location Zones (LZ)

The Sydney Opera House site is divided into areas A to F with an attached numeric code for subdivisions of the complex.





Note: Location Zone definitions for remote facilities to be advised.

Location Zones shall be represented by ifcZone

ifcZone

IFC Attribute	Setting
Name	One of LZ codes from Table A.2 above
Description	Not applicable
Object type	“Location Zone”
Long name	Not applicable
Complex type	Not applicable

Property Set usage is project and task dependent and shall be determined by Sydney Opera House.

Functional Spaces (FS)

Organisational units within the Bennelong Point complex are termed Functional Spaces. Table A.3 below sets out the current scope.

Table A.3: Functional Space Codes

FS Code	FS Name	FS Definition
AE	Arts Exchange	Arts Exchange
BG	Building (general)	Works (including overheads & operations) not to a specific functional space, all plant rooms, general arrangements, total site plans/layouts
BX	Box Office	Box office, Call centre, Tours Office, Box office foyer including cloakrooms, toilets, stairs from forecourt
CH	Concert Hall	Auditorium including walls & ceilings, platform, backstage, control rooms, roof space (not shells), foyers, rehearsal & dressing rooms
CP	Central Passage	Stage door, central passage and bronze vehicle doors

DT	Drama Theatre	Auditorium, stage, backstage, control rooms, rehearsal & dressing rooms
FB	Food & Beverage	Facilities provided specifically for food and beverage services (Bennelong Rest, Cafe Mozart, Sidewalk Cafe, Opera Bar, 180 Degree, Dolce vita and any food/beverage contract space)
FC	Forecourt	Forecourt, upper podium, lower forecourt, broadwalks (eastern, northern, western), toilets
OT	Opera Theatre	Auditorium including walls & ceilings, backstage & dock, control rooms, roof space (not shells), foyers, rehearsal & dressing rooms
PH	Playhouse	Auditorium, stage, backstage, control rooms, rehearsal & dressing rooms
UR	Utzon Room	Hall and side rooms, access to Hall
RS	Recording Studio	Recording Studio and Edit Suite
SF	Staff	Facilities Staff and contractor areas, including corridors and common areas, not covered elsewhere including Green Room
SH	Shops	Facilities provided specifically for retail
ST	Studio	Auditorium, stage, backstage, control rooms, rehearsal & dressing rooms
WF	Western Foyer	Foyer and toilets, Exhibition Hall

Note: Functional Space definitions for remote facilities to be advised.

Functional Spaces shall be represented by the entity *ifcZone* linking *all* rooms contained in the Functional Zone

ifcZone

IFC Attribute	Setting
Name	One of FS codes from Table A.3 above (excluding BG Building (general)
Description	One of FS names from Table A.3 above (complementing the matching FS code)
Object type	“Functional Space”
Long name	Not applicable
Complex type	Not applicable

Property Set usage is project and task dependent and shall be determined by Sydney Opera House.

2.5.3 Rooms (RM)

Rooms are an area that is defined by the building’s major wall elements etc, (potentially not able to be removed).

Rooms in the Bennelong Point complex are numbered according to the following convention: <Storey code><sequential number>. The *Storey cod*e is either a character code eg SB or a number eg 1. Room names are documented on existing GA plans. See Base Building Architectural drawings.

Eg GM574A Upper Plantroom #14 or 1527C Green Room Dining

Note: Room name definitions for remote facilities to be advised.

Sydney Opera House Room Types

ID	Type	ID	Type	ID	Type
1	Circles & Boxes	17	Lounge	33	Plantroom
2	Auditorium Stalls	18	Food Servery	34	Storage
3	Toilet and Airlock	19	Kitchen	35	Workshop
4	Public Foyer	20	Cool Room	36	Balcony
5	Box Office	21	Shop	37	Podium
6	Cloak room	22	Lift Well	38	Monumental Stairs
7	Rehearsal room	23	Lobby	39	External Stairs
8	Dressing Room	24	Stair	40	Lower Concourse
9	Wardrobe	25	Services Corridor	41	Forecourt
10	Control Rooms	26	Cleaners Room	42	Car Concourse
11	Stage Storage	27	Tea Room	43	Western Broadwalk
12	Stage/Backstage	28	Executive Office	44	Northern Broadwalk
13	Equipment Room	29	Manager's Office	45	Eastern Broadwalk
14	Locker Room	30	Meeting Room	46	Shells & Louvres
15	Bar Servery	31	General office		
16	Dining Area	32	Services Duct		

All *rooms* in the Sydney Opera House shall be defined as an entity *ifcSpace*.

ifcSpace

IFC Attribute	Setting
Name	*Room number* as defined above
Description	Not applicable
Object type	*Room type* – the functional category of the room (according to Sydney Opera House room type classification above)
Long name	*Room name* as defined above (complementing the matching Room number)
Complex type	Not applicable
Internal/External	As applicable; a room is external if it bounds an external face of the building.
Elevation wrt flooring	Height in mm from storey level on which it is located

Property Set usage is project and task dependent and shall be determined by the Technical Information Officer who is responsible for maintaining the Room Schedule and issuing new room attributes.

Places (PL)

Places are sub-divisions of a room, ie the "child" of a Room (see above).

> **Note**: The FAPI database records BPI against *Places,* however the main reporting mechanism presents the Place scores wrapped up to its parent room.

A *place,* within a room, is identified by adding a suffix to the room id (eg for room G539A, *G539A/1* is the first place within the room).

All Places in the Sydney Opera House shall be defined as an entity *ifcSpace* and linked to their owning Room by an *ifcZone*.

IfcSpace - Place

IFC Attribute	Setting
Name	*Place number* as defined above
Description	Not applicable
Object type	“Place”
Long name	Not applicable
Complex type	Not applicable
Internal/External	As applicable; a place is external if it bounds an external face of the building.
Elevation wrt flooring	Height in mm from storey level on which it is located

IfcZone - Place

IFC Attribute	Setting
Name	*Room number* as defined above
Description	Not applicable
Object type	Not applicable
Long name	Not applicable
Complex type	Not applicable

8.5 The Site Model & GIS

The Sydney Opera House main complex is located on a site overlaid by a complex network of historical development, archaeological artefacts, current and disused utilities, underwater and underground features. Information about this is sourced from many private and state utilities and government agencies, and in many different but principally GIS formats.

The objective of the Master Model is to integrate this data in IFC format.

Cadastre

Cadastral data elements are a designated discipline and shall conform to Section 8.3 Sydney Opera House Sub-models when exchanging data.

Land Use

Land use data elements are a designated discipline and shall conform to Section 8.3 Sydney Opera House Sub-models models when exchanging data.

Terrain

Terrain elements are a designated discipline and shall conform to Section 8.3 Sydney Opera House Sub-models when exchanging data.

Utilities

Utilities elements are a designated discipline and shall conform to Section 8.3 Sydney Opera House Sub-models when exchanging data.

Asset Register

Where model entities are part of the Sydney Opera House Asset Register, data shall be attached to the entity in the form of a custom PSET, named “Sydney Opera House Asset Register”, and shall conform to the following:

IFC PSET “Sydney Opera House Asset Register”

IFC Property	Setting
Reference	*Asset Reference ID* as defined by Sydney Opera House Asset Register
Description	*Asset Description* as defined above (complementing the matching asset item *Name)* eg "Lift No. 06")
Element	Sydney Opera House Asset element classification Eg *"*Transportation*"*
ItemLocation	Sydney Opera House *Room number* (see section above)*
Functional Space	See *FZ codes* above*
Parent	Owning *Plant reference* eg "BG1141 Lifts"
BarCode	The Sydney Opera House bar code
InstallDate	Date of purchase (dd mmm yyyy format)
InstallCost	Cost in AUD of installing item
PurchaseCost	Cost in AUD of purchasing item

*** Note**: This data may be derived directly from the IFC model data

Property Set usage is project and task dependent and shall be determined by Sydney Opera House.

8.6 The Architectural Model

Building Elements

Building elements (the term used in the IFC specification to describe the main building parts) are the most numerous in the model; where possible the following information shall be recorded:

Property	
Material (and layers) – in accordance with Australian Building Glossary or other definitive industry reference	*FireRating* – in accordance with BCA
AcousticRating - in accordance with BCA	*Combustible*
SurfaceSpreadOfFlame	*ThermalTransmittance*
LoadBearing	*Compartmentation*

This data shall be applied to the relevant property set eg for walls PSET_WallCommon, or if no such standard PSET exists then a custom PSET.

5.2 Slab, Beam, Column, Wall, Window, Door, Ramp, Stair and Railing Elements
Architectural elements are a designated discipline and shall conform to Sydney Opera House Sub-models when exchanging data.

Note that all ifcEntities have a standard PSET which may be applicable according to the specific project and task.

Compartmentation & Fire Zones

Fire zones correspond to the Location Zones described earlier. Smoke compartmentation shall be a subdivision of the LZ in accordance with the BCA and relevant authorities. All smoke compartments shall be defined in accordance with *Location Zones* above.

Structural Engineering

Structural elements are a designated discipline and shall conform to Sydney Opera House Sub-models when exchanging data.

8.7 Building Services

Refer to the Building Services Standard Specification (BSSS and BSDM Building Services Designers Manual) for detailed design and performance criteria.

Mechanical Services

Mechanical Services elements are a designated discipline and shall conform to Sydney Opera House Sub-models when exchanging data.

Electrical & Digital Communications

Electrical Services and Digital Communications elements are both designated disciplines and shall conform to Sydney Opera House Sub-models when exchanging data.

CAVS (Stage & Audio-visual Equipment)

CAVS elements are a designated discipline and shall conform to Section 8.3 Sydney Opera House Sub-models when exchanging data.

Security

Security elements are a designated discipline and shall conform to Section 8.3 Sydney Opera House Sub-models when exchanging data.

Hydraulic Services

Hydraulic elements are a designated discipline and shall conform to Section 8.3 Sydney Opera House Sub-models when exchanging data.

Transportation

Transportation elements are a designated discipline and shall conform to Section 8.3 Sydney Opera House Sub-models when exchanging data.

Equipment

Equipment elements are a designated discipline and shall conform to Section 8.3 Sydney Opera House Sub-models when exchanging data.

8.8 Asset Maintenance & Presentation

The following information is vital for asset maintenance and presentation.

Where model entities are part of Sydney Opera House asset maintenance or presentation, data shall be attached to the entity in the form of a custom PSET, named "Sydney Opera House Asset Maintenance" and "Sydney Opera House Building Condition Index" respectively and shall conform to the following:

Maintenance

IFC PSET "Sydney Opera House Maintenance"

Property	Setting
Name	*Plant Reference* as defined by Sydney Opera House eg "BG1147"
Description	*Plant Description* as defined above (complementing the matching asset item *Name* eg "Lift No. 06")
Element	Sydney Opera House Asset element classification Eg "Transportation"
ItemLocation	Sydney Opera House *Room number* (see section above)*
Functional Space	See *FZ codes* above*
Parent	Owning *Plant reference* eg "BG1141 Lifts"
Name	*Plant Reference* as defined by Sydney Opera House eg "BG1147"
Maintenance Task Schedule	The Sydney Opera House maintenance *Task Allocation* code

Note: refer to the *IFC PSET "Sydney Opera House Asset Register"* in Section Asset Register

Building Condition Index

The *Building Condition Index* (BCI), a combination of a Building Fabric Index (BFI) and a Building Presentation Index (BPI), is a method the Sydney Opera House has adapted to measure general appearance, tidiness and cleanliness of functional spaces of the building.

The BPI data shall be described in a custom IFC PSET "Sydney Opera House Building Condition Index"

IFC Property	Setting
Name	*Asset Element* or *Place* as defined above
Description	*Asset name* as defined above (complementing the Asset name)
BFI Date	*dd/mm/yyyy* date the *Fabric Index* was measured
BFI Rating	*% rating* (see Sydney Opera House BFI Scoring Structure)
BFI Target	% rating to be achieved
BFI Benchmark	Reference rating
BFI Note	Comments made at the measurement inspection
BFI Inspection Name	Reference for inspection
BPI Date	*dd/mm/yyyy* date the Presentation Index was measured
BPI Impression	*% rating* (see Sydney Opera House BPI Scoring Structure)
BPI Cleanliness	*% rating* (see Sydney Opera House BPI Scoring Structure)
BPI Tidiness	*% rating* (see Sydney Opera House BPI Scoring Structure)
BPI Target	*% rating* to be achieved
BPI Benchmark	Reference rating
BPI Note	Comments made at the measurement inspection
BPI Inspection Name	Reference for inspection

8.9 Model Auditing

Model Data to be submitted for update of the Sydney Opera House Master Model shall be audited[9] before submission. There are several levels of auditing:

Sydney Opera House BIMSS compliance
IFC project data for controlled collaboration
Model entity geometry & properties
Model veracity

8.10 Sydney Opera House BIMSS Compliance

The IFC file data must comply with all of this specification's requirements, such as setup of the model, the naming of stories, buildings, rooms etc.

Whenever an IFC model is created certain data is mandatory. The entities described in Appendix B**,** Table 4: IFC Model – High level Entities are termed the *IFC Project Data*.

An IFC Project may have multiple buildings and multiple sites, even if the receiver has only imported one of several buildings in an IFC source file. In the IFC model each story has a collection of building elements, described by geometry and property data.

Data for the high level entities is always exported, even if the export is filtered to a certain storey or excludes geometry data for example. For reliable collaboration, *the GUIDs for the high level entities **must** be identical with the Sydney Opera House Master Model* to allow updating and merging. New entities (excluding the Project) may occur, but agreement from Sydney Opera House must be given before creating these new entities.

Model Entity Geometry & Properties

The IFC specification supports many geometry representations. Consult with Sydney Opera House to ensure that your application's IFC data meets these requirements.

All geometry shall be properly constructed so that abutting or related elements are represented faithfully.

Ensure that attribute data (mandatory properties required by the IFC specification) and Property set data (PSETs) meets Sydney Opera House information, material etc standards.

Model Veracity

A model may meet the above criteria but still be unacceptable – for example a room might have no door. Ensure that model is consistent and logically correct.

---

[9] **Note**: Several commercial tools are available for this purpose, eg *Solibri Model Checker*, Finland, *NavisWorks Jetstream*, UK and *DesignCheck*, CRC for *Construction Innovation*, Australia. IFC model servers such as *EDM Model Server*, EPM Norway and *Eurostep Model Server*, EuroSTEP also perform many customisable and sophisticated model auditing functions.

9. SHOWCASE: IFC Building Information supporting AM/FM for Sydney Opera House

9.1 Introduction

Several high-level processes have been identified that could benefit from standardised Building Information Models:

- maintenance processes using engineering data
- business processes using scheduling, venue access, security data
- benchmarking processes using building performance data

Linking this data together can support these processes even further. For example:

- Quickly find the responsible person/contract when an element fails.
- Retrieve all objects (walls, doors, etc) scoring on the BPI below x which have had a major maintenance
- Retrieve all history of cleaning scores of objects before and after a new cleaning contract for comparison
- List the location of assets and their performances including maintenance history
- Query vacated spaces and their Building Fabric Index scores
- Simulate and visualise the effect of taking a service out of commission
- The integration of (heterogenous) information sources supports the alignment of different processes. For example space planning and maintenance operations can benefit from integrated planning.

9.2 An Overview of an Integrated FM System for Sydney Opera House

Figure 9 represents an overview of a framework for an integrated FM system for the Sydney Opera House.

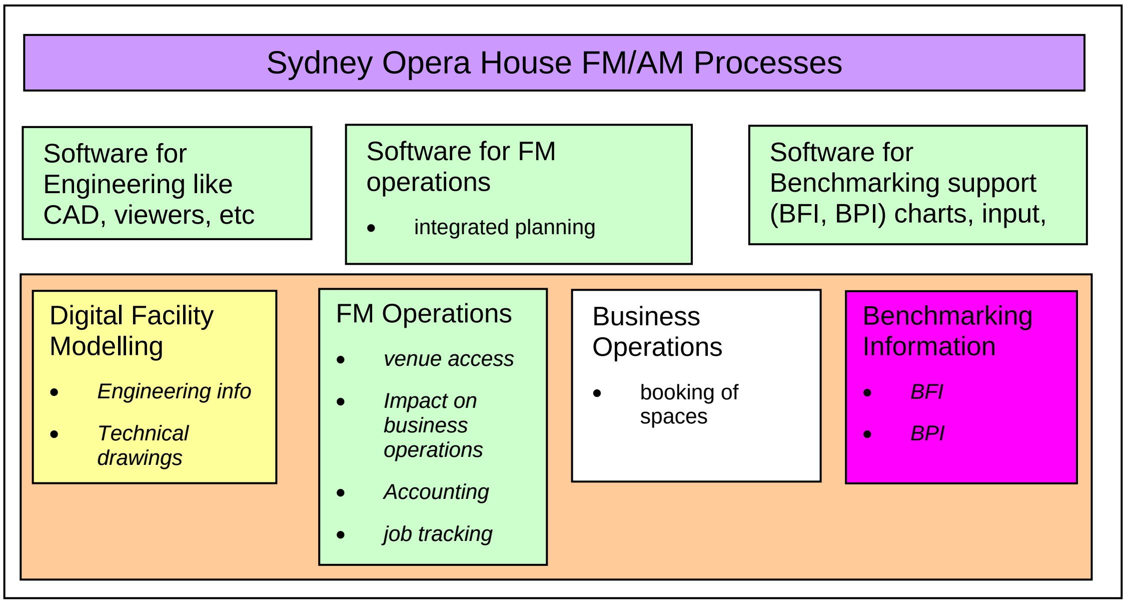


Figure 9: Digital facility modelling supporting Sydney Opera House's FM processes.

Obviously the information environment can be extended by many other sources of information such as OHS, etc. Eventually the system can become the body of knowledge for Sydney Opera House storing best practices and implementing rules on top the information environment reducing risks and mistakes. For example the system could flag when certain spaces are performing under a certain threshold or make suggestions regarding maintenance planning.

9.3 Showcase

The showcase demonstrates and tests the potential of Digital Models for the FM industry.

Sydney Opera House specific information

The integrated FM system needs to deal with Sydney Opera House specific information such as Sydney Opera House building decomposition and specific information such as BFI, BPI, etc. The following screenshot demonstrates the usage of a Building Information Model which incorporates a part of the Sydney Opera House decomposition. In addition the objects in the BIM have properties such as BFI and BPI.

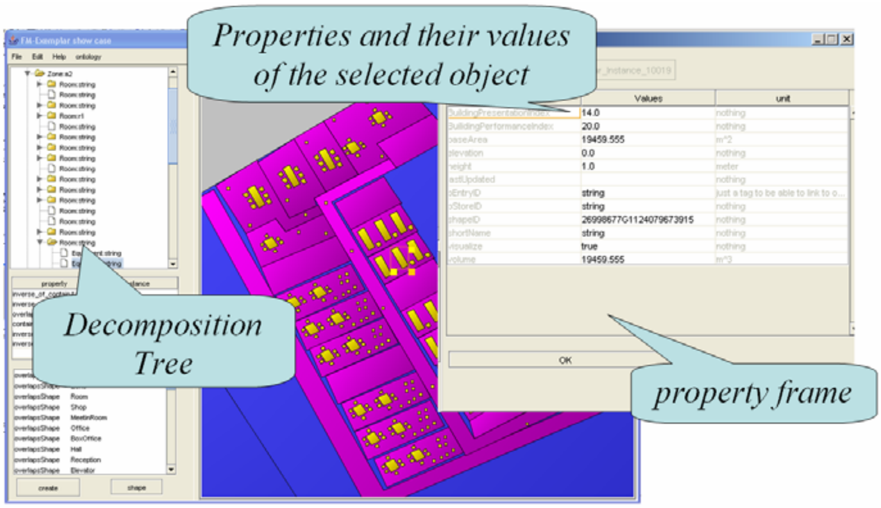


Figure 11: Objects such as building, storey, zone, room, chair are organised in a tree similarly as Sydney Opera House building organisation structure. All objects have properties containing specific information such as BPI and BFI values. The objects, properties and their relation form the framework for the building model.Visual Reporting

The results of queries with colour coding techniques can be used to present the information using the building geometry. For example results of queries such as retrieving all objects with a certain performance index can be visualised (figure 10).

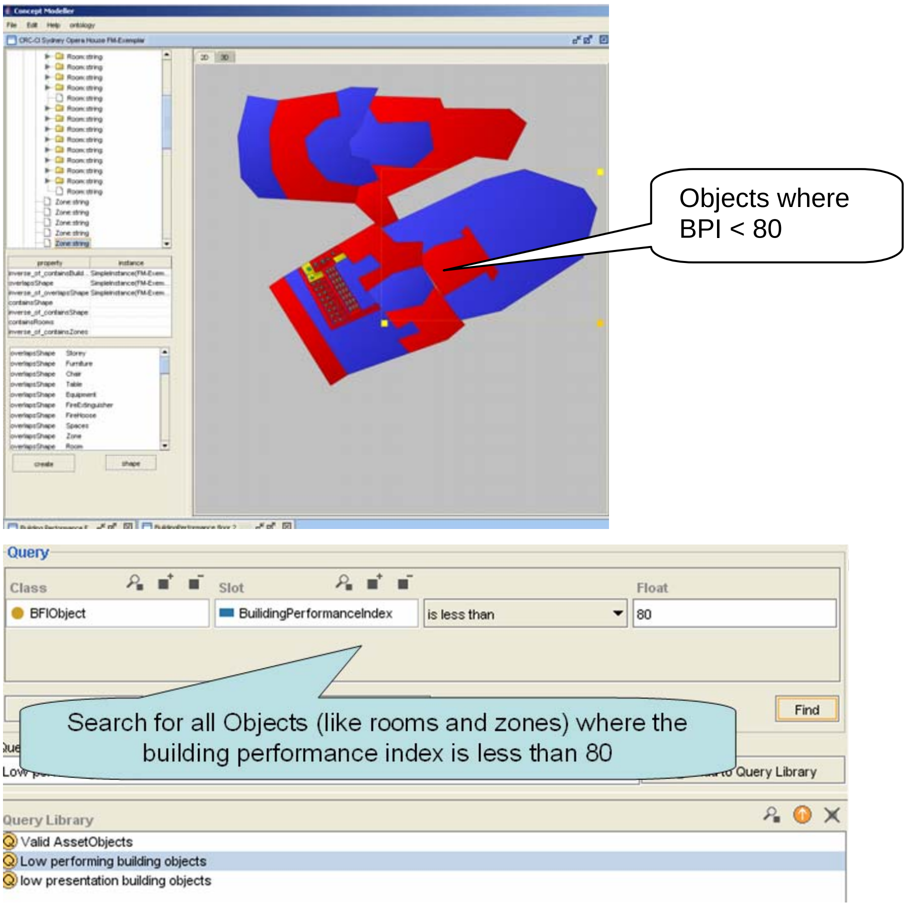


Figure 12: Visualising results of queries

The following screenshot shows an example where all the zone scores have been colour coded.

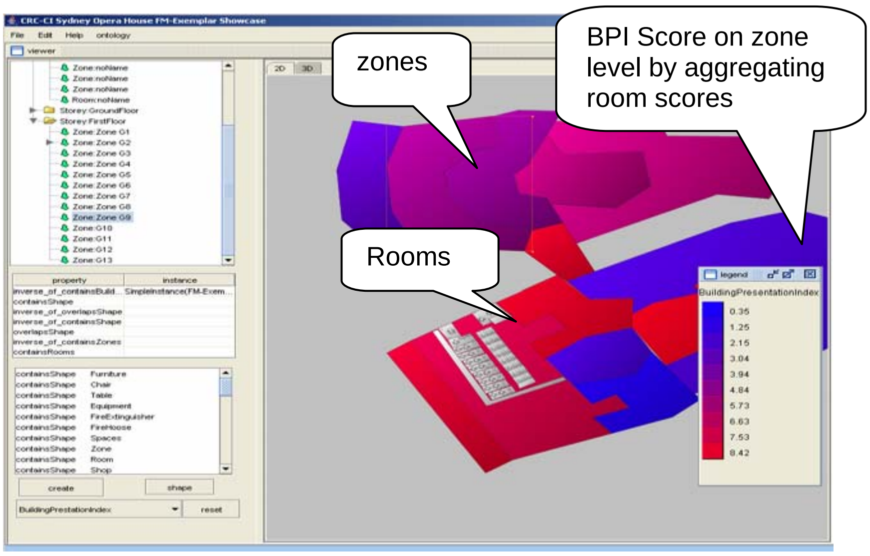


Figure 13: An example of how to present BPI and BFI more graphically by color coded indices

Adding Intelligence

Rules can be created working as an added layer of business intelligence using the raw, yet comprehensive data of the integrated database. For example BPI and BFI scores can be calculated automatically for zones. This can be done by aggregating the scores of objects 'in' the zone.

Other types of rules can help assess what will happen when for example a certain service is failing. The following example shows what happens when power is cut in one of the rooms. The system automatically shows the rooms affected by this action.

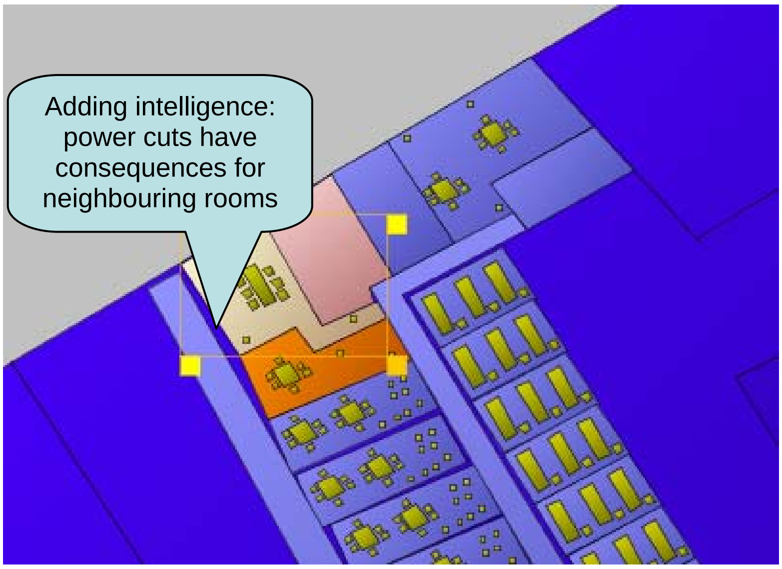


Figure 14: Computing and visualising the impact of taking a service out of commission

9.4 Interoperability using the IFC

CAD interoperability

To gradually develop a digital facility model, the usage of IFC has been proposed. To demonstrate the feasibility of IFC based data, Arup's structural model has been exported from Bentley's Microstation in IFC format. This file has been imported in ArchiCAD without loss of data and then extended with rooms. From ArchiCAD a new expanded export in IFC format has been used in the showcase software used by CSIRO.

This modest, but informative, test has confirmed that a partial model of the House could be created. Where possible, this test model adopted the standards proposed in the draft BIM Standard Specification for Sydney Opera House. Structural, Architectural and Analysis applications were able to share and collaborate with the same model data.

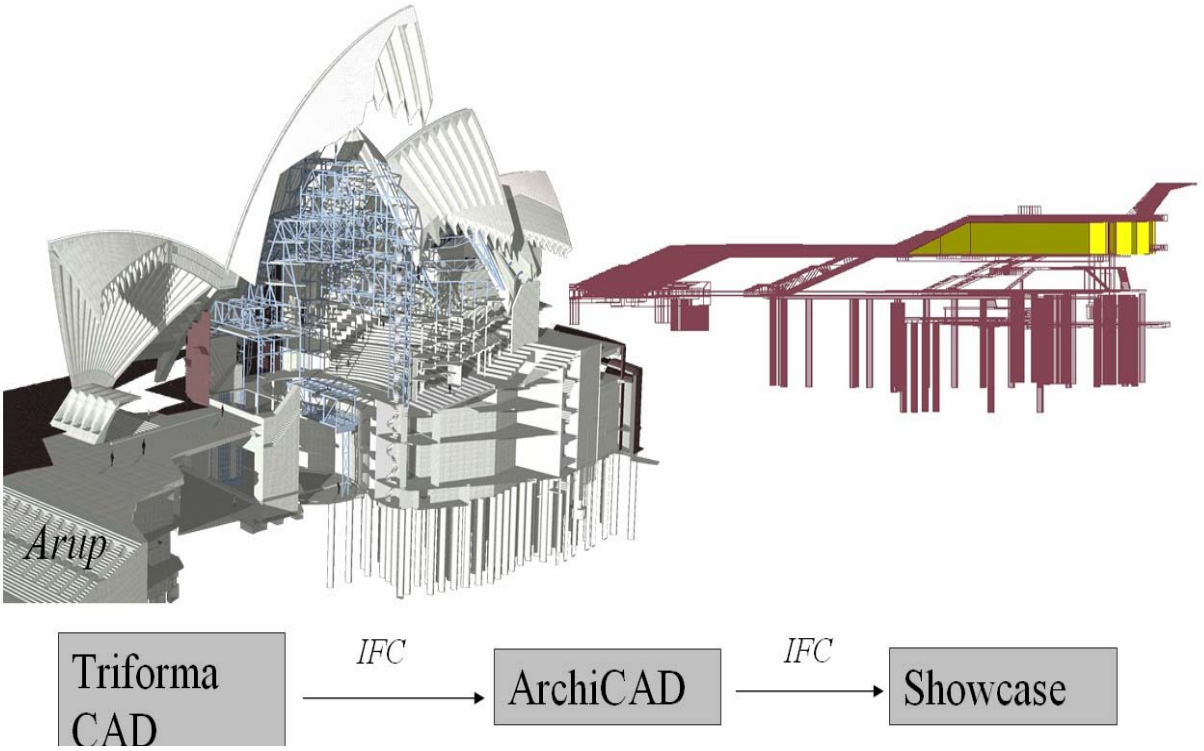


Figure 15: IFC interoperability between different software systems.

Extending the model with Benchmarking

Figure 16 is a simplified data model for storing and retrieving benchmarking data. The data model defines zones having several functional spaces. The functional spaces contain elements such as doors, walls, etc. Several elements are already available in the Digital Facility Model such as the elements, doors, walls, etc. Such a schema can easily be implemented in a relational database such as a SQL DB.

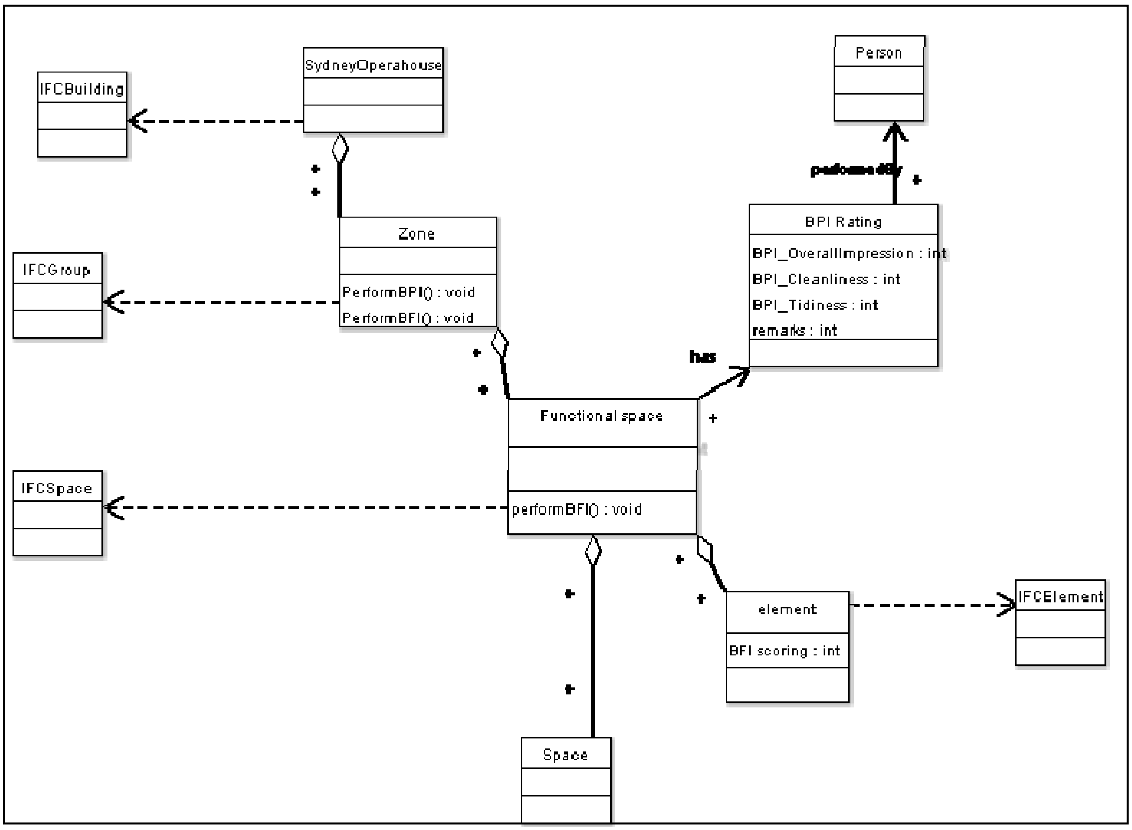


Figure 16: Simplified data-model for supporting benchmarking including relations to the IFC

This specific Sydney Opera House data-model can be linked with a standardised building information model such as the IFC. For example functional Spaces can be linked with the IFC Space (figure 17).

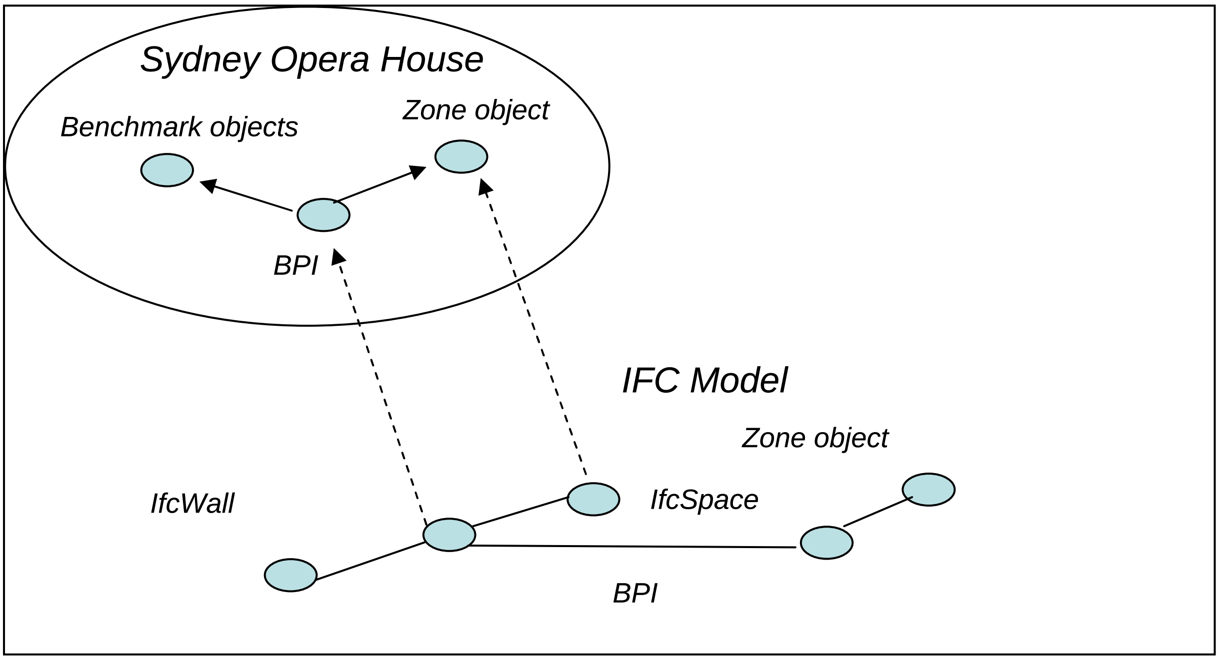
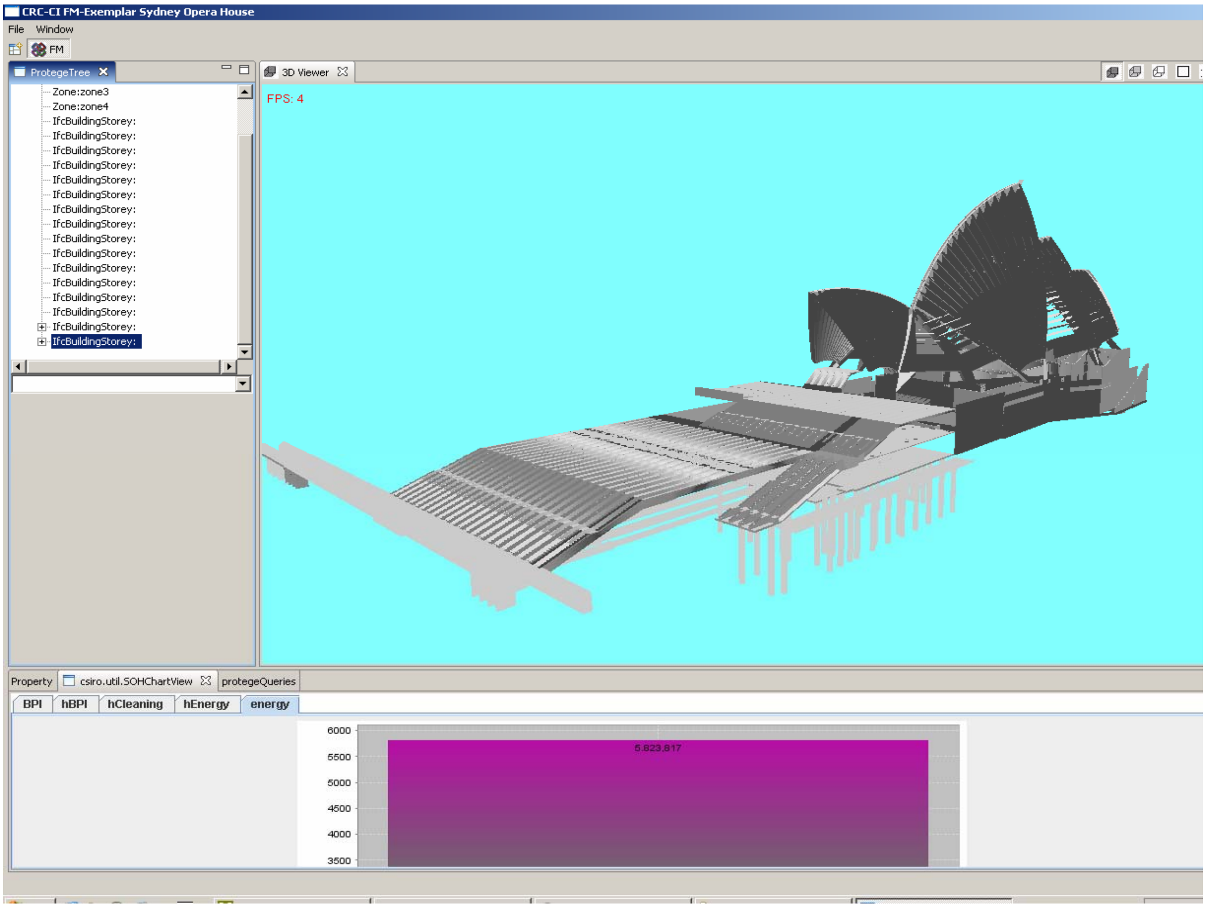


Figure 17: adding company specific information.

The result is an integrated model combining the IFC with a benchmarking data model. This approach has been implemented resulting in a system re-using IFC data extended with Sydney Opera House specific functionality such as BPI history data, etc (figure 18).



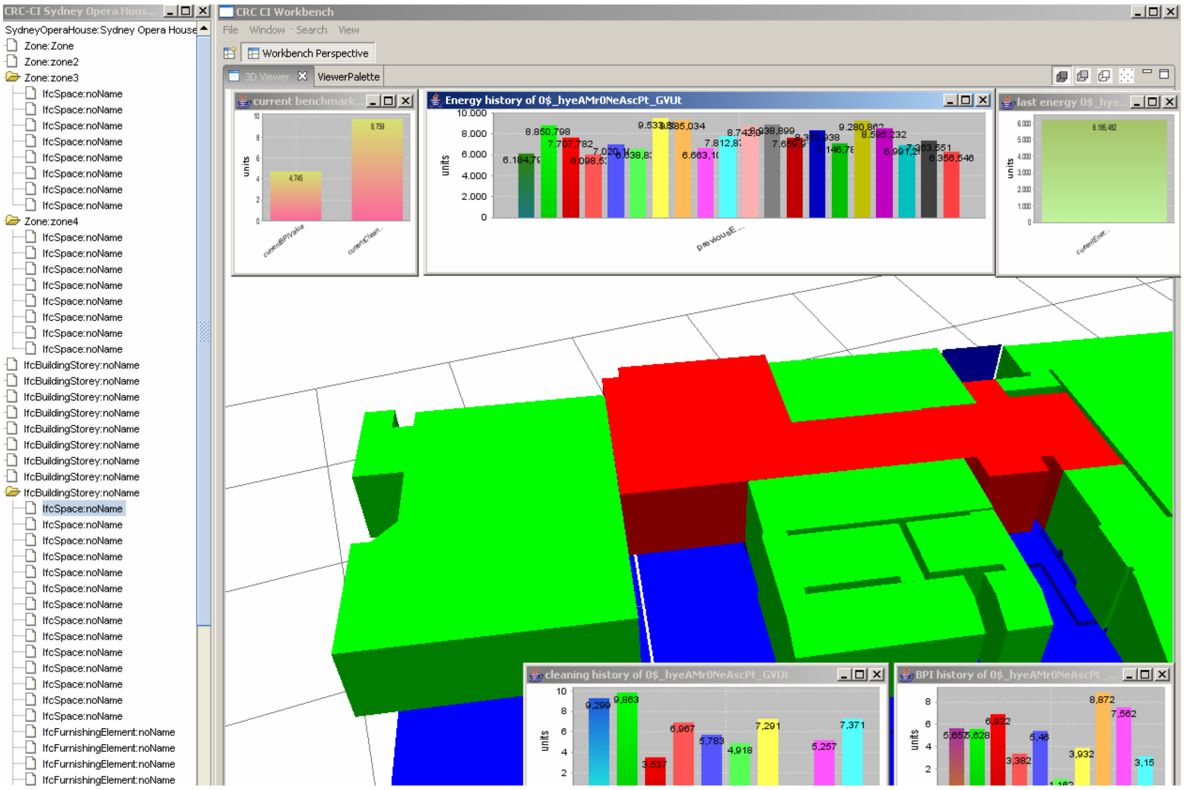


Figure 18: IFC based showcase extended by Sydney Opera House benchmark model

This showcase demonstrates the re-use of the IFC model for FM purposes and demonstrates the potential of extending the IFC with more organisation specific information.

9.5 Technical Recommendations

Centralised Approach

Temporarily setting aside existing tools and infrastructure, an ideal situation would be to have an integrated data model containing all relevant information for Sydney Opera House for different departments (Figure 19). Such a data model would have a benchmarking module containing the necessary benchmarking data. All other necessary data would be re-used. The data would be reasonably maintainable. However the applications need to be compliant with this data model. It seems that extending the IFC data model could potentially be such a data model. In addition a heterogenous solution containing for example a SQL database and links to the IFC model is also feasible.

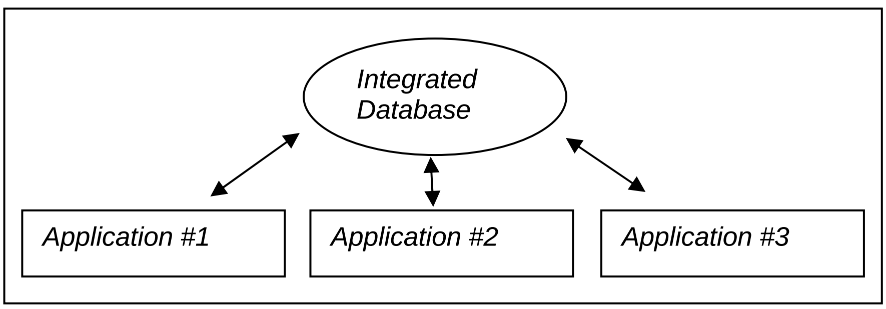


Figure 19: Integrated data model.

Decentralised Approach

Already several systems are installed such as 'MainPac' and space planning software. These software systems have their own database or data storing mechanism. Overlap of information can be present. This means that similar information resides in different databases resulting in redundancy. In order to keep all systems up-to-date changes in the data must be communicated to several other databases. Integration of these databases means that these relationships have to be determined and implemented (Figure 20). When many applications are available the amount of relationships can increase rapidly.

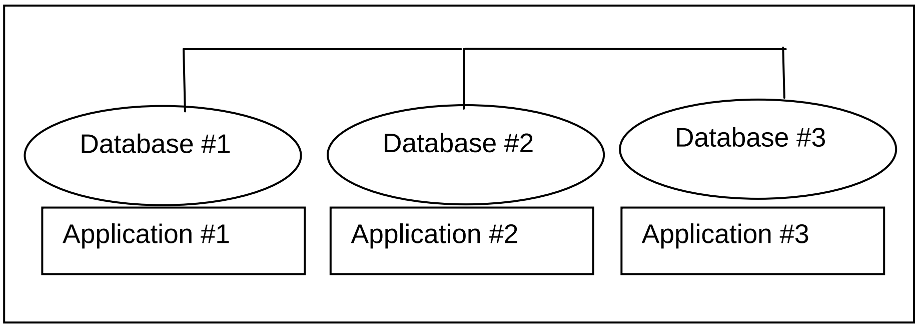


Figure 20: Decentralised approach.

The decentralised approach is also a feasible approach. Nowadays standardised communication languages are available. Querying over different systems and combining its information is possible. A simple interface could be the based around the unique ID of each element. For example a room planning calendar service could provide booking information based on a room ID (and a date). The maintenance calendar could do the same thing for maintenance operations. Location service could provide the location of an element by submitting its ID. Software applications can use these services to provide its users more information (Figure 21).

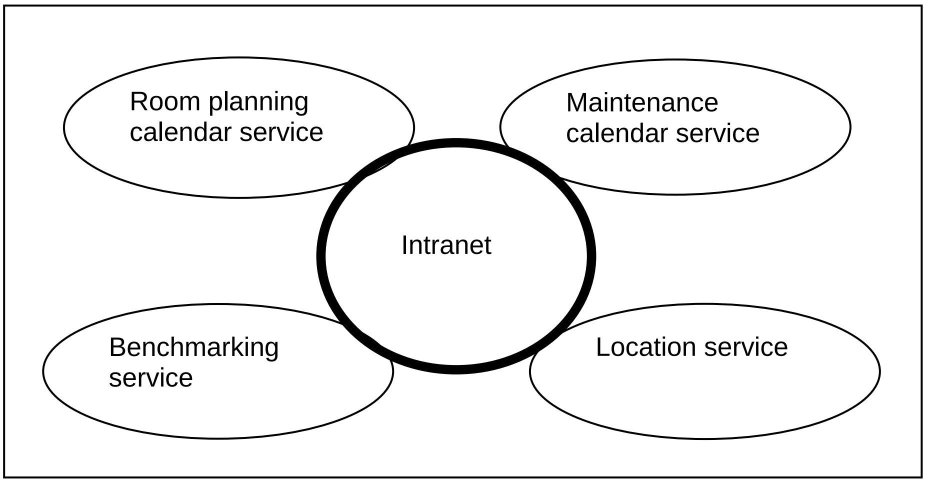


Figure 21: Potential Web services for Sydney Opera House

An advantage of these web services approach is that the systems are loosely coupled. Updating a system or completely replacing one can be done without problems when the service is kept the same. In addition new services can join the intranet in order to deal with future extensions.

10. Key Findings and Recommendations

10.1 Findings

The project has established the following:

BIM – building information modelling - is an appropriate and potentially beneficial technology for the storage of integrated building, maintenance and management data for Sydney Opera House

Based on the attributes of a BIM, several advantages can be envisioned:

- *Consistency* in the data. Data is accurate and multiple versions of the same data are eliminated.
- *Intelligence in the model*. For example *windows* are automatically related to walls and cannot be located otherwise. A *switchboard* is part of a logical network of circuits, is geometrically described and is located spatially in a room on a storey of the building. Changing the height of a wall automatically updates relationships, quantities, etc.
- *Multiple representations* such as 2D drawings, 3D views, bills of quantities, logical connections (a building services system schematic)
- *Source of information for intelligent programs*. For example several CAD packages offer capabilities for sunlight analysis, acoustic performance and sustainability rating etc.
- *Intelligent queries* such as how many steel beams are in the model > 2 metres, etc or which fire-rated doors have a current compliance certificate?

The IFC – open building exchange standard – specification provides comprehensive support for AM / FM functions, and offers new management, collaboration and procurement relationships based on sharing of intelligent building data.

The major advantages of using an open standard are:

- The information can be read and manipulated by any compliant software;
- Reduced user “lock in” to proprietary solutions. Third party software can be the “best of breed” to suit the process and scope at hand;
- Standardised BIM solutions consider the wider implications of information exchange outside the scope of any particular vendor;

The information can be archived as ASCII files for archival purposes.

Data quality can be enhanced as the now single source of users’ information has improved accuracy, correctness, currency, completeness and relevance.

Sydney Opera House current building standards have been successfully drafted for a BIM environment and are confidently expected to be fully developed when BIM is adopted operationally by Sydney Opera House

There have been remarkably few technical difficulties in converting the House’s existing conventions and standards to the new model based environment. This demonstrates that the IFC model represents world practice for building data representation and management.

Sydney Opera House has already implemented data quality checks to improve reliability and synchronisation of data which is a good platform for further development

Availability of FM applications based on BIM is in its infancy but focussed systems are already in operation internationally and show excellent prospects for implementation systems at Sydney Opera House

In addition to the generic benefits of standardised BIM described above, the following FM specific advantages can be expected from this new integrated FM environment:

Faster and more effective processes – information is more easily shared, can be value-added and reused;

The IFC specification allows for any number of *user or project specific properties* according to a common format. This is one area where proprietary BIM solutions may constrain users. In some proprietary systems it is very difficult for an ordinary user to add additional properties;

- *Controlled whole life costs and environmental data* – environmental performance, maintenance and investment is predictable, life-cycle costs can be analysed and understood;
- *Better customer service* – information can be accessed in multiple formats appropriate to each user ie. seating plans are understood through accurate visualisation;
- *Common operational picture* for current and strategic planning – as model data is inter-related developing scenarios and their impacts (such as budgeting for major maintenance, assessing security or understanding dislocation during construction activity) can be understood more easily leading to better decision making;
- *Visual decision-making* – allows executives, management and lay users (particularly) to understand the nature and relationships of the facility, eg building services failures through graphic 3D or abstract views generated from the model, etc;
- *Total ownership cost model* – all aspects of the facility including building usage and operations are in a single integrated repository.

Tests with partial BIM data – provided by several of Sydney Opera House's current consultants – show that the creation of a Sydney Opera House complete model is realistic, but subject to resolution of compliance and detailed functional support by participating software applications

The showcase has demonstrated successfully that IFC based exchange is possible with several common BIM based applications through the creation of a new partial model of the building. Data exchanged has been geometrically accurate (the Sydney Opera House building structure represents some of the most complex building elements) and supports rich information describing the types of objects, with their properties and relationships.

A Benchmarking System, already in use for a Building Presentation Index (BPI) for example, can be derived from the BIM model; whilst there are several options in detail, an ideal situation would be to have an integrated data model containing all relevant information for Sydney Opera House for various departments. Such a data model would have a benchmarking module containing the necessary benchmarking data. All other necessary data would be re-used. The data would be reasonably maintainable. However software applications need to be compliant with this data model.

10.2 Recommendations for Sydney Opera House

In summary, this study has identified a technology solution that can be implemented at Sydney Opera House. An immediate benefit would be a description of information flows in the process and provide options for organisational and technical solutions to improve process efficiency. It would form an important road map to identify a technical and organisational frame work for improvement.

It is recommended that:

1. Sydney Opera House adopt standardised BIM for the support of asset and FM functions and proceed with the development of an Implementation Plan
2. Sydney Opera House presents these findings to appropriate Government agencies and seeks evaluation of this report with a view to its adoption in NSW as the standard for the exchange of information in the Built Environment

There are many factors about which this study team has neither knowledge nor a brief to consider, in particular funding, current asset and facility planning and operations, capital improvements, committed work etc.

The recommendations below are thus aimed at providing a guide to the main steps needed to proceed with the conversion to a BIM based building information environment.

The key steps needed for the Sydney Opera House to proceed to implementing BIM are outlined below:

- Form a BIM Implementation Committee to manage the process with representatives from all relevant internal and external parties, directed by Sydney Opera House
- Develop a budget for a (staged) implementation of the model
- Collaborate with interested parties – reporting agencies, consultants, suppliers, users and the Sydney Opera House FM technical team to determine the availability and acquisition of operational BIM software to support model creation and management
    - Evaluate CAD tools that can edit model data and possibly host integrated data
    - Review Model Server options
    - Evaluate hardware needs for the above
- Work with appropriate stakeholders to pilot BIM modelling and IFC exchange to certify they support, comply and can collaborate according to the new Sydney Opera House standards and procurement procedures
    - Ratify the draft BIM standards, in particular with the key disciplines of architecture, structure and building services.
- Commence implementation in a sequence for example as follows:
    - Implement small discipline Sydney Opera House partial sub-models
    - Audit the existing Opera Hall sub-model to see how it complies with the Sydney Opera House BIMSS
    - Develop a plan to upgrade it, extend all the relevant discipline data and create a preliminary Sydney Opera House partial master model.
    - Review technology capabilities (servers etc) to suit the project master model
    - Develop a plan for the completion of the master models

- Liaise and regularly report on the BIM implementation with NSW Government and industry as a model of future information management, collaborative processes and potential for innovation

In parallel

- Develop a FM implementation plan to convert to the new BIM environment
    - Specify and procure an application
    - Audit the current systems and develop a staged conversion
    - Implement of convert trail benchmarking data

Work with external suppliers and contractors to develop procurement systems based on the Sydney Opera House BIM model.

10.3 Recommendations for the Facilities Management (FM) Industry

Standardised Building Information Modelling as an integrated information source for FM processes including business processes is feasible.

- IFC offers interoperability between CAD systems enabling re-use of building information
- The IFC model is standardised making the data more future proof
- Already commercial FM software systems are available using IFC data
- Other related software such as energy prediction models and on-site monitoring are available using IFC data
- The IFC model is extensible and can incorporate organisation specific requirements

It is recommended that:

- the FM industry adopt IFC for the sharing of asset and facility management information
- the FM Action Agenda with related organisations evaluate this report with a view to adopting IFC as a national standard for the exchange of information for the Management of Built Environment.

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